JOURNAL

OF THE

AMERICAN SOCIETY OF AGRONOMY

VOLUME 25

1933

PUBLISHED BY THE SOCIETY

CONTENTS

No. 3. MARCH

No. 4. APRIL

No. 5. MAY

No. 6. JUNE

No. 7. JULY

No. 8. AUGUST

No. 9. SEPTEMBER

No. 10. OCTOBER

No. 11. NOVEMBER

No. 12. DECEMBER

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 JANUARY, 1933 NO. 1

HISTORY OF THE ORGANIZATION OF THE AMERICAN SOCIETY OF AGRONOMY[1]

T. LYTTLETON LYON[2]

The history of the American Society of Agronomy traces to a date preceding its organization. There was a period of preparation. A time when conditions were so shaping themselves that the formation of the Society was a logical development. It was this that insured the immediate success of the organization.

During the last few years of the nineteenth century and the early part of the present one there began in the agricultural colleges a disintegration of the old departments of agriculture into units of more limited range. Among the offshoots was agronomy. The same movement took place in the Federal Department of Agriculture. Carleton in the first presidential address to this Society, stated that in 1900 there were only three agronomists in the agricultural colleges. Appointments in Agronomy increased so rapidly that in 1908 there were 99 persons holding that title. An equally rapid development of the subject took place in the U. S. Dept. of Agriculture. In 1900 the term was not used in the Federal Department but a few appointments of agronomists and assistant agronomists were made in 1901. By 1908 these appointments had increased to at least 100. I do not intend to convey the impression that agronomic work was not done before the closing years of the last century. Previous to that time, however, it was conducted in a somewhat restricted way by persons who bore other titles, and who in most instances conducted other lines of work as part of their official duties. The segregation of agronomy into a separate unit and the specialization which went with it created a need on the part of agronomists for contact with men in similar lines of work.

Many departments of agronomy in the agricultural colleges included such subjects as farm mechanics and farm management. However, these subjects were never considered to be within the field covered by this Society. Article II of the Constitution reads: "The

[1]Presented as the report of the Historian of the Society as part of the anniversary program commemorating the first twenty-five years of the Society's life.

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object of the Society shall be the increase and dissemination of knowledge concerning soils and crops and the conditions affecting them." Accordingly, the papers presented at meetings of the Society did not include any on farm mechanics or farm management, even during the early life of the organization.

As a consequence of the advanced stage of development of agronomy at the time of the formation of the Society, the organization experienced no difficulty in maintaining its existence at any subsequent period. The 101 charter members became 121 by the close of the first year. In 1909 the roll was increased by 26 new members and in 1910 by 46 new members. In the latter year the total membership was 176, only 14 persons having fallen by the wayside during the first 3 years. The roll published in 1926 contained 653 names and today the membership comprises 949 persons. In addition to every state and territory in the Union, and nearly every province in Canada, the following countries are represented on its rolls: Argentine, Australia, Brazil, British West Indies, British Guiana,China,Ceylon, Colombia, C echoslovakia, Cuba, Denmark, England, Estonia, Dominican Republic, Dutch East Indies, Egypt, Finland, Fiji, France, Germany, Greece, Holland, Honduras, Haiti, India, Ireland, Italy, Japan, Jugoslavia, Mauritius, Mesopotamia, Mexico, Morocco, Norway, Peru, Poland, Portugal, Roumania, Spain, South Africa, Sweden, Switzerland, Turkey, Uruguay, Russia, Wales, West Indies, and Federated Malay States.

The total number of memberships outside of the United States and Canada is 74. This does not include Hawaii, Phillipine Islands, Porto Rico, or other outlying portions of the United States, which are also represented.

The first move towards the formation of a national Society, entirely covering but limited to the field of agronomy, took place in Washington, D. C. Action was taken at one of the meetings of the Agronomic Seminar of the U. S. Dept. of Agriculture in the fall of 1907. Even at this early date the Seminar was a very active one. A committee consisting of M. A. Carleton, W. J. Spillman, C. V. Piper, E. C. Chilcott, and A. D. Shamel was appointed to ascertain the opinions of agronomists throughout the various states, and also of certain college presidents, directors, and others, concerning the advisability of organizing such a Society. The following letter which was sent out has not been printed in the records of the Society and is therefore recorded here:

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PLANT INDUSTRY

GRAIN INVESTIGATIONS

Washington, D. C., Nov. 30, 1907

DEAR SIR:

At the last meeting of the Agronomic Seminar of this Department the undersigned were appointed a committee to propose the formation of an American agronomic society. This committee is authorized by the Seminar to invite other men to serve with them on a final committee which shall call a meeting of all persons interested in agronomy at Chicago during the time of meeting of the American Association for the Advancement of Science this coming holiday

season, for the purpose of organizing such a society. You are hereby respectfully invited to be a member of this final committee. As soon as acceptances of these invitations are received a call for the meeting will be at once issued.

There are a number of reasons for the existence of such a society several of which are so self-evident that it seems hardly necessary to discuss them in detail at this time. It is probably sufficient for the present to call attention to the fact that although the study of field crops and their relation to soil and climate is so important and has come to be considered in recent years of more and more importance, there is no society in this country at present giving attention to this subject, except the Corn Association recently organized, which is limited in its field of action to *one* of the many important field crops.

It is suggested that the committee issuing the call for this organization meeting have, as far as possible, every thing ready to facilitate a speedy organization, thereby leaving more time for the society itself to give attention to other matters besides business. In addition to the suggestive outline of the purposes and plans of the society, a draft of the constitution and by-laws should be presented as a basis of action for the society and it is probable that even a provisional program could be gotten together. In view of the short time now preceding the holiday season it is highly important that we receive an answer from you as soon as possible. Please give your opinion of the desirability of forming such an organization and make any suggestions concerning the subject that come to mind. Give titles and time required for any papers you can present.

Signed:
M. A. Carleton
W. J. Spillman
C. V. Piper
E. C. Chilcott
A. D. Shamel

The letters received in reply to this communication are in the archives of this Society. It is not known how many of the circular letters were mailed, but 58 replies were received. It is quite noticeable that many of the administrative offices were inclined to question the desirability of adding another society to the list to which they might be expected to pay dues, although they did not express the feeling in those words. However, the agronomists were almost unanimous in the opinion that a society of agronomists should be organized.

As a result of the canvass another letter was sent out on December 12 announcing a meeting to be held in Chicago on December 31, 1907, during the week in which the American Association for the Advancement of Science was to meet in the same city. This letter had attached to it the names of 38 persons who were willing to sign the call for a meeting and to assist in the organization of a Society. The letter was printed in the Proceedings (Vol. 1, page 6) of the Society, and will not be reproduced here.

Last year a list of charter members of the Society now on the rolls was printed in the report of the Historian. This needs some revision and the list is therefore inserted here in full, with present addresses.

C. R. Ball, University of California
J. A. Bizzell, Cornell University
H. L. Bolley, N. Dak. Agr. College
B. E. Brown, U. S. Dept. of Agriculture
Lyman Carrier, Coquille, Oregon
G. A. Crabb, University of Georgia
E. O. Fippin, McLean, Virginia
F. D. Gardner, Pennsylvania State College
A. F. Gustafson, Cornell University
J. N. Harper, Atlanta, Georgia
Alvin Kezer, State Agr. College, Colorado
A. F. Kidder, Galesburg, Ill.
J. G. Lipman, Rutgers University
T. L. Lyon, Cornell University
A. G. McCall, U. S. Dept. of Agriculture

M. F. Miller, University of Missouri
C. A. Mooers, University of Tennessee
R. A. Moore, University of Wisconsin
M. L. Mosher, University of Illinois
Oswald Schreiner, U. S. Dept. of Agriculture
H. L. Shantz, University of Arizona
C. F. Shaw, University of California
L. H. Smith, University of Illinois
W. H. Stevenson, Iowa State College
R. W. Thatcher, Massachusetts State College
J. D. Tinsley, Santa Fe R. R., Amarillo, Texas
L. R. Waldron, N. Dak. Agr. College
J. M. Westgate, University of Hawaii
H. J. Wheeler, Upper Montclair, N. J.
A. R. Whitson, University of Wisconsin
A. T. Wiancko, Purdue University
C. G. Williams, Ohio Agr. Exp. Station
E. L. Worthen, Cornell University

So far as possible, photographs of these charter members taken somewhere near the date of the founding of the Society have been collected, and are reproduced herewith.

Covering as wide a range of subjects as soils and field crops, including the breeding of these crops, it was inevitable that papers should be classified according to subject matter. Accordingly, the first program committee appointed was instructed to provide for two sections, one for papers on soils and the other for papers on field crops. This differentiation of the program was prompted, or at least insured, by a move already on foot at the time of the formation of the Society to start an organization in the Mississippi Valley to deal with the subject of soils. The persons who had conceived the plan then joined the Agronomy Society with the idea of incorporating this embryo organization in the larger society.

These two sections have remained active during the first quarter century of the life of the Society. No others have been formed, although proposals to do so have been discussed several times. Perhaps a substitute for further differentiation of the program has been found in the custom of holding symposia in some closely restricted field. The first symposium was held about 1920, apparently at a special meeting in December of that year. The original idea was to have a review of the literature of some subject, bringing it up to date, and discussing all of its phases. This was particularly useful to busy men who did not have time to do this themselves, and especially to those who were in colleges not well provided with library facilities.

Gradually, however, the form of presentation changed. It became less a review of literature and more a discussion of the speakers' own work on the subject assigned. Naturally the leader of the symposium selected speakers on account of their own interest and accomplishments in the field of research chosen for the discussion. As there are nearly always to be found several persons working in closely related lines, a symposium really constitutes a temporary section of the Society devoted to the presentation of research in a particular field. In consequence the call for subdivisions of the Society into many sections has become less marked in recent years. By means of symposia it is possible to have a temporary section on any subject desired.

There is no one to whom the Society is more indebted, or perhaps so much indebted, as to those persons who have borne the burdens that

C. R. Ball

J. A. Bizzell

H. C. Bolley

B. E. Brown

Lyman Carrier

G. A. Crabb

E. O. Fippin

F. D. Gardner

A. F. Gustafson

J. N. Harper

Alvin Kezer

A. F. Kidder

J. G. LIPMAN

T. L. LYON

A. G. McCALL

M. F. MILLER

C. A. MOOERS

R. A. MOORE

M. L. MOSHER

OSWALD SCHREINER

H. L. SHANTZ

C. F. SHAW

L. H. SMITH

W. H. STEVENSON


R. W. THATCHER


J. D. TINSLEY


H. G. WHEELER


A. R. WHITSON


A. T. WIANCKO


C. G. WILLIAMS


E. L. WORTHEN

fall upon the editors of its publications. Editorial duties call for wide knowledge, powers of discrimination, tact, and courage, besides almost daily attention to the details of the work.

At the second annual meeting of the Society, held in Omaha, December 7 to 8, 1909, it was voted that an editing committee of five be appointed, the Secretary of the Society to be, *ex-officio*, secretary of the committee, and that the proceedings of the Society be published in as large an edition as was possible with the funds in hand. Carleton R. Ball, who had been elected Secretary of the Society, thus became editor. Under his editorship were published Volumes 1 to 4 of the PROCEEDINGS of the Society. These contained the papers presented at the meetings from 1907 to 1912, inclusive.

In 1913, Dr. Ball began publication of the JOURNAL of the American Society of Agronomy, provision having been made by the Society for publication of a journal to contain papers in addition to those presented at the meetings. The JOURNAL was issued quarterly in 1913. Dr. Ball continued the editorship through 1914. That year five numbers of the JOURNAL were published.

In January 1915, C W. Warburton began his duties as Secretary and Editor. The JOURNAL was increasing in size nearly every year and the papers were becoming more technical. This made the editorial work more exacting. To relieve the Editor, the position of Secretary was combined with that of Treasurer in 1917. Dr. Warburton was thus able to devote more time to the editorship, which duties he continued to perform until the close of 1921. Six numbers of the JOURNAL were issued in 1915 and also in 1916, nine in 1917, eight in 1918, and nine in 1919. In 1920 it dropped back to seven numbers, and in 1921 and 1922 the practice of publishing eight numbers was resumed.

With the beginning of 1922, Roscoe W. Thatcher became Editor. This position he held until the close of 1928. Most of that time he had the help of James D. Luckett, who was named Assistant Editor in 1923. That year was the first in which 12 numbers were issued and this has been maintained to the present time. Since January 1929, the editorship of the JOURNAL has been entirely in the hands of Mr. Luckett.

Up to the close of 1930 there have been 1,322 separate papers printed in the JOURNAL, in addition to records of the transactions, reports of committees, book reviews, resolutions, and other miscellaneous matter.

The holding of meetings and the publication of papers have been the two most important functions of the Society. The former of these has fallen on many shoulders, but the latter has been carried throughout the past quarter century by the four men I have named. During all this time the PROCEEDINGS and the JOURNAL have been ably edited. On this function of the Society we may look with profound pride.

It has always been rather difficult to finance the JOURNAL, which has been almost entirely dependent on membership dues for its support. The Society began life with the modest annual fee of $2.00 per member. This was continued until 1918 when it was rather gingerly raised to $2.50. There was always a fear that a more adequate fee would result in reduced membership.

In 1917 there were 652 members, which was the largest roll attained to that date. In 1918 the number dropped to 509 and continued to descend until 1920, when it reached 436. This was so evidently due to the influence of the war, and its aftermath, that any effect of the 50 cent rise in dues is entirely masked.

By 1922 the membership had risen to 643. The JOURNAL was having a hard struggle. A courageous committee recommended that the annual dues be increased to $5.00. The Society endorsed this stand and the increase took effect in the beginning of 1923. That year there was a loss of 82 members. However, in 1924 the roll increased by 16 members and in 1925 the membership stood at a higher figure than before the change in fee took place. From that time there has been a larger membership each year up to the present time. The larger revenue has made possible a great improvement in the JOURNAL, which has doubtless been reflected in the increased membership.

The close of the first quarter century in the life of the American Society of Agronomy finds that organization in the most successful period of its career. The membership is the largest in its history, the meetings are more largely attended, and the papers published in the JOURNAL are more scholarly than ever before. While the outlook for the immediate future does not encourage the hope of a pronouncedly continued increase in membership, owing to the general retrenchment in expenditures by the agricultural, as well as other scientific institutions, yet there is every reason to believe that the quality of the work will at least continue on its present high plane.

A QUARTER CENTURY PROGRESS IN SOIL SCIENCE[1]

JACOB G. LIPMAN[2]

When the American Society of Agronomy was established in 1907, a substantial foundation had already been built for the new science of soils. The term Pedology, as descriptive of the entire field of soil research was proposed at the international soil conferences at Budapest in 1909 and Stockholm in 1910. It is still used in a more or less qualified way in some of the European countries. Recent trends, however, are toward the use of the more inclusive term "Soil Science" and its counterparts "Bodenkunde" in the German, "Pochvovyedeniye" in the Russian, and "La Science du Sol" in the French languages.

A review of the developments in this field of science can deal, at best, with only the major features of a story full of significant and interesting accomplishments. There are the historical antecedents of the era with which we are now concerned. Legislation, enactments, and the authorization of funds were factors of moment. Departments and institutions had to be established, technicians appointed, laboratories built and equipped, and experiments planned. With the research facilities thus created it became possible to undertake the devising of methods and the invention of special apparatus as expedients for the collection of a large body of facts. The next step involved the grouping and classification of the accumulated data, their interpretation, and their fitting into a larger pattern which we call generalization. Following that, we were ready for hypotheses and theories of soil fertility more adequate than those which were the products of speculation and abstraction rather than of well planned research. Finally, we see the application of soil research to policies of conservation and of land use.

This report has to do with the grist from the mill of soil research. It has to do, also, with the mill itself. It is a composite of the efforts of our colleagues in the Bureau of Chemistry and Soils and in Rutgers University. In your behalf, as well as for myself, I wish to express

[1]Presented as part of the anniversary program commemorating the first twenty-five years of the Society's life.

[2]Director, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

our indebtedness for help cheerfully given by Doctors McCall, Schreiner, Knight, and Professors Blair, Waksman, Mattson, Joffe, Shive, Starkey, Prince, Lee, and Nightingale.

THE HISTORICAL BACKGROUND

In the introduction to his book "The Soil" whose first edition appeared in 1902, A. D. Hall says:—"The crude chemical point of view, which in the main regarded the soil as a nutritive medium for the plant, has been altogether extended, by a consideration of the soil as the seat of a number of physical processes affecting the supply of heat and of air and water to the plant, and again as a complex laboratory, peopled by many types of lower organisms, whose function is in some cases indispensable in others noxious, to the higher plants with which the farmer is concerned. These three kinds of reaction—chemical, physical and biological—interact upon one another and upon the crop in many ways." In the preface to the second edition which was published in 1908, Sir Daniel says:—"A considerable number of additions and alterations have been incorporated in the present edition. These include a revision of the method recommended for the mechanical analysis of soils.... Owing to researches which appeared since the publication of the first edition I have greatly modified the views I then expressed on the nature of clay, and on the part played by zeolitic silicates in the retention of ammonium and other salts by the soil. During the last six years, however, the greatest additions to our knowledge of the soil are those dealing with bacteria; in consequence, the chapter on the living organisms of the soil has been largely rewritten and added to."

In the preface to "Fertilizers and Manures" by the same author and dated December, 1908, the following statements occur:—"The use of some form of fertilizer is becoming more and more a mark of modern agriculture." Further on he says:—"It is the continual introduction of plant food from outside which distinguishes modern intensive methods of cultivation from the old farming." And again:—"The cost of production has begun to rise in the new countries, already we see the American farmer is in his turn being compelled to resort to fertilizers; and with each rise in prices the intensive farmer can recoup himself for an increased outlay." He tells us, also, that:—"A good deal of the material in the book has already been utilized and in part published in a course of Canter Lectures delivered before the Society of Arts in 1906, and again in a course of lectures delivered at Cornell University to the Graduate School of Agriculture ....in July, 1908."

In his preface to "Soils" dated at Berkeley, California, November 15, 1905, Hilgard has this to say:—"It is certainly true that mere physico-chemical analyses, unassisted by other data, will frequently ead to a wholly erroneous estimate of a soil's agricultural value, when applied to cultivated lands. But the matter assumes a very different aspect when, with the natural vegetation and the corresponding cultural experience as guides, we seek for the factors upon which the observed natural selection of plants depends by the physical

and chemical examination of the respective soils. It is further obvious that, these factors being once known, we shall be justified in applying them to those cases in which the guiding mark of native vegetation is absent, as the result of causes that have not materially altered the natural condition of the soil.

"Soils" by Lyon and Fippin was published in December, 1909. In the preparation of the book the authors were guided by certain points of view well illustrated by the following quotation:—"The kinds of minerals and rocks in which the essential elements of plant-food originally occur, and the changes which they may have undergone in their transition to the present combinations in the soil, as well as the fact that the physical properties of the soil are primarily determined by its derivation, render their study of fundamental concern in order to understand the soil as a medium for plant-growth. The classification and detailed study of the soil is inseparably linked with its derivation, because determined by it. On one side, it supplies certain elements of food whose relative abundance is determined by their distribution in the original rocks and their concentration or dissipation through geological changes, and, on the other side, it affords the physical medium for the development of the plant.

We find a different approach to soil research in "Soil Fertility and Permanent Agriculture" by Hopkins. The book was copyrighted in 1910. "It is the business of every farmer," says the author, "to reduce the fertility of the soil, by removing the largest crops of which the soil is capable; but ultimate failure results for the land owner unless provision is made for restoring and maintaining productiveness. Every land owner should adopt for his land a system of farming that is permanent—a system under which the land becomes better rather than poorer." Farther on he states:—"Phosphorus and decaying organic matter are the two substances which constitute the key to profitable systems of permanent agriculture on most of the normal soils of America; although, when soils become sour, or acid, ground natural limestone should also be regularly applied at the rate of about two tons per acre every four to six years."

Still another approach to the study of soils is found in "Bodenkunde für Land-u. Forstwirte" by Mitscherlich. In the preface dated May, 1905 he stresses the point that the growth of plants is determined by the existing physical and chemical condition of the soil rather than by its geological origin. The following quotation, though somewhat lengthy, is justified by the importance of the point of view expressed and as indicating the subsequent trend of his soil investigations. He says:—"Alle Erscheinungen in der Natur lassen sich auf Energievorgänge zuruckfuhren, welche sich in verschieden langer Zeit vollziehen. Die verschiedenen Arten dieser Energievorgänge behandelt die Physik und die Chemie—zwei Wissenschaften, welche somit als die Grundlage aller übrigen Naturwissenschaften betrachtet werden müssen. Auf ihnen bauen sich demnach die anderen Naturwissenschaften auf. Die Geologie z. B. betrachtet die physikalischen und chemischen Gesetzmässigkeiten in ihrer Einwirkung auf die Erdrinde und so hier u. a. die Entstehung des Bodens. Die Botanik und insonderheit der für den Land- und Forstwirt wesentlichste Teil

derselben, die Pflanzenphysiologie, untersucht die chemischen und physikalischen Bedingungen, unter denen die Pflanzen wachsen, und so von diesem Gesichtspunkte aus die physikalische und chemische Beschaffenheit des Bodens.—Man hat bislang fast stets diese pflanzenphysiologische Bodenkunde von der geologischen in direkte Abhängigkeit zu bringen versucht, ohne sich klar zu machen, dass das Bindeglied zwischen beiden, das einzig Gemeinsame der Beiden Wissenschaften, die Grundwissenschaften, Physik und Chemie, sind. Wohl ist die Beschaffenheit verschiedener Bodenarten je nach ihrer Entstehung physikalisch und chemisch verschieden, wohl können die Unterschiede, welche auf die geologische Abstammung eines Bodens zurückzufuhren sind, auch pflanzenphysiologisch als Unterschiede zu bezeichnen sein, trotzdem müssen wir beides scharf trennen, denn *es ist für unsere Kulturpflanzen ganz gleichgultig, wie der Boden, auf dem sie wachsen, einst geologisch entstand; das Gedeihen der Pflanzen wird sich stets danach richten mussen, wie der Boden momentan physikalisch und chemisch beschaffen ist.*"

Ramann's "Bodenkunde" reflects the rather rapid evolution of the conceptions of soil fertility toward the end of the last century and within the first decade of the present century. His first book appeared in 1895. The second edition, a substantial revision of the first, was printed in 1905. In the preface to the third edition, published in 1910, the author emphasizes the important revisions that he had been obliged to make. One of the concluding sentences in this preface is significant:—"Das Vorliegende Buch behandelt die Bodenkunde abs Wissenschaft."

The views outlined in Cameron's "An Introduction to the Study of the Soil Solution" are in part foreshadowed in Bulletin 22 of the Bureau of Soils. This bulletin by Whitney and Cameron, entitled "The Chemistry of the Soil as Related to Crop Production", was published in 1903. It became the subject of much controversy since it ran counter to the accepted theories of soil fertility.

Later on Cameron in his "An Introduction to the Study of the Soil Solution" was led to modify, in some measures at least, the opinions expressed by Whitney and himself in Bulletin 22.

The soil solution was considered to be of first "importance in the investigation of the relation of the soil to plant growth, and in the following pages there is given an outline of our present knowledge of the chemical principles involved, with such discussion of the physical and biological factors as is essential to an orderly presentation of the subject."

The biochemical point of view received increasing attention, among students of soils, during the first decade of the present century. In 1907 there was published by the Office of Experiment Stations a bulletin entitled "A Review of Investigations in Soil Bacteriology" whose authors were Voorhees and Lipman. In the following year Lipman's book "Bacteria in Relation to Country Life" appeared. All that shows that the significance of microorganisms as a factor of soil fertility was gaining recognition.

The same author contributed four chapters on soil microbiology to Marshall's "Microbiology" which was first published in 1911. The

treatment is based on the conception of the soil as a culture medium of microorganisms.

The biochemical point of view, but by a different method of approach, is likewise set forth in Russell's "Soil Conditions and Plant Growth." Several revised and successively improved versions of the book have been contributed by the author. Historically, it would be worth while to reproduce the preface to the first edition. This preface is dated at Harpenden, January, 1912, and is as follows:—

"I have endeavoured in the following pages to give a concise account of our present knowledge of the soil as a medium for plant life. At first sight the subject appears very simple; in reality it is highly complex and trenches on several different subjects with which no one individual can claim to have any adequate knowledge, and, what is perhaps a greater disadvantage, it has grown up very unsystematically. Chemists, botanists, bacteriologists, geologists, and agriculturists have all contributed something, but usually in connection with their own special problems and not with the idea of developing a new subject. It has usually been reckoned part of the somewhat vague mixture known as agricultural chemistry, and has often been considered more suitable for farmers' lectures than for pursuit for its own sake."

THE ORIGIN, FORMATION, AND CLASSIFICATION OF SOILS

Soil studies of far-reaching importance were being carried on by Russian investigators in the last quarter of the 19th century. The facts and their interpretations, as they had been developed by these investigators at the time of the founding of the American Society of Agronomy, are given in Glinka's "Pochvovyedeniye" published in St. Petersburg in 1908.

Glinka knew soils from intimate contact, as a leader of many soil expeditions, as a moving force in the colonization projects promulgated by the old and new Russian governments for the settling of the wide stretches of that vast country known as Siberia. He was equipped for his researches with the tools of mineralogy, geology, botany, physics, and chemistry. His contributions extend to the various branches of soil science, but his outstanding work is soil genesis. As a pupil, assistant, and follower of Dokuchaev, the founder of the genetic school of soil science, he tested the new science, developed it and described it in his monumental work "Pochvovedenie." A unique contribution of Glinka, sometimes overlooked, are his researches on the buried soils which offer a great array of facts not only to pedologists but also to geologists and climatologists. This work of Glinka involved the participation of his intimate friend and associate Poluinov.

Outstanding work in the same field was done by Prasolov, Zakharov, Afanasiev, and Neustruev.

An imposing figure in the realm of soil science within the last 25 years is that of Gedroiz. He attained world-wide reputation for his remarkable researches on the complex capable of ionic exchange and on soil colloids. Many puzzling soil phenomena were clarified by him

through the application of physico-chemical methods. One of his outstanding achievements is the elucidation of the chemical, physical, and physico-chemical transformations that take place in the profile make-up of solonchak, solonetz, and solodi, the three steps in the evolution of the process of alkali soil formation. From a study of the ion exchange reactions Gedroiz went as far as building a system of soil classification based on physico-chemical properties of the soil.

With the work of Gedroiz as a guide and stimulus Vilenskii delved into the problem of the origin and genesis of alkali soils. There is probably no more thorough analysis of this problem—save perhaps that of Sigmond from Hungary—than that of Vikenskii's. It has the advantage over all other works of a similar nature in that it is in harmony with the fundamental ideas of Dokuchaev. Vilenskii is also to be associated with work of soil classification. His treatise "The classification of soils on the basis of analogous series in soil formation" is thorough, original, and very instructive.

The list of Russian contributions, for the given period, could be augmented. We may mention those of Ototzkii, Vuisotzkii, Morozov, Vernadskii, Kravkov, Gemmerling, Krasyuk, Tanfiliev, Berg, Dimo, Sokolovskii, Tumin, Lebedev. (A bibliography of their work may be found in Glinka's book). These and a score of others investigated the various phases of soil science and brought together a wealth of material on the different types of soil formation, on forest soils, hydrology, mineralogy, soil solution, soil chemistry, soil geography, etc. And all of these investigations radiate from one central idea and revolve about the fundamental principle of soil science, namely, that the soil is a natural body.

Outside of Russia the researches on soil genesis are—with few exceptions—meager. This phase of soil science which originated in Russia is still new to the Western world, but notable beginnings have been made.

In Germany the savant of soil science, Ramann, contributed in a very large measure to the knowledge of the evolution of soils. In his later years Ramann was influenced by the genetic school of soil science and his work reflected these influences. He was probably the first among the Western pedologists to place soil science on an independent basis. To Ramann soil type meant more than texture, although he did not fully appreciate the concept of climatic zonality of soil types. It is of interest to note that Ramann came to soil science from forestry where soils may be studied as a natural body.

Stremme's work in recent years has been prompted by an appreciation of the genetic relationships existing in the soil profile.

A more significant contribution in expounding the physico-chemical reactions in the soil-forming processes has been made by Wiegner and his pupils Meyer and Jeny. The ionic exchange and other properties of the soil colloid complexes have been the subject of his researches. He applied his findings to the vexed problem of soil classification. His pupil Jeny attempted to use the Lang P/T (precipitation over temperature) ratio and the Meyer N/S quotient (Niederscheag for N and saturation coefficient for S) in classifying the soils of Europe and North America. In his earlier work Jeny dealt with the zonation of

soils in the Alpine region. One should not forget the work of Murgoci and his pupil and follower Saidel on the soils of Roumania.

In Hungary Treitz and Sigmond made notable contributions on the genesis of alkali soils.

In the United States Hilgard's work stands out as a classical example of the American school of soil science which combined agronomy and soils into one unit. And yet the views of Hilgard on the genesis and classification of soil embodied in a large measure the principles of the genetic school of soil science.

Due importance should also be attached to the work of Whitney who as the Chief of the Bureau of Soils had an interest not only in his particular field of physico-chemical reactions of soils but in all other phases of soil science. He even had some notion about the modern ideas of soil genetics as shown by his correspondence with Dokuchaev. A summary view on soils with a philosophical tinge is to be found in Whitney's book "Soil and Civilization."

Nor should we forget the monumental work of Van Hise to whom the soil workers the world over are indebted for guidance in the elucidation of the prerequisite of soil-forming processes, the process of weathering.

The work of Marbut stands out as one of the distinct contributions made by American workers. He was among the first of the Western workers to appreciate the new ideas about soils. Equipped with the sciences of geology, mineralogy, and geography, Marbut quickly oriented himself in the complexities of the Russian system of soil science and adopted the methods in a comprehensive study of the soils of the United States. Today Marbut's views on the genesis of soils, as applied to the soils of the United States, or better, the American continents, are probably as far reaching as those of the outstanding pedologists of Russia. His numerous contributions are well known and an expression of his ideas on soils may be found in one of his latest publications. We should anticipate with keen expectation his forthcoming work on "The Soils of the United States."

SOIL SURVEYS, CLASSIFICATION, AND MAPPING IN THE UNITED STATES

For the past twenty-five years the field of soil classification, survey, and mapping have been largely influenced in the United States by Whitney and Marbut. Their leadership has inspired noteworthy contributions from many others, the sum total of which marks two and a half decades of most commendable progress. During this period in the United States, according to Knight, "A high degree of accuracy has been reached in making soil maps. Soil surveying represents the mechanics of a new science......in recent years a stage of development has been reached which combines fundamental scientific principles with accuracy in soil classification......Since 1899, more than 1100 areas have been surveyed aggregating over 800,000,000 acres." In the earliest period of the history of the Bureau of Soils, soil classification and differentiations were made mainly upon the basis of texture. It was the belief of Professor

Whitney that texture was one of the primarily important characteristics to be recognized in soils in order to obtain information regarding the most correct and economical crop adaptations. Field experience soon made apparent the necessity of taking into consideration other characteristics, such as color, topography, and drainage, both surface and internal.

The constant progress has been marked by several outstanding publications beginning perhaps with Bonsteel's paper on "Important American Soils" published in 1911. In this work, the more important soils are located, described, and their utilization discussed. In 1912, Coffee issued a paper entitled "A Study of the Soils of the United States" which discussed the nature and origin of soils in general, their classification and the occurrence, location, and identification of various soils found in this country. An elaborate bibliography accompanies this work. Marbut and others published "Soils of the United States" in 1913, a most useful and very comprehensive volume setting forth the progress of the Soil Survey and describing in detail the various soil Provinces and the soil series and types found in each, together with their extent, and a key to the identification of the various soil series of each Province. In 1915 Wilder produced a paper entitled "Soils of Massachusetts and Connecticut with Especial Reference to Apples and Peaches." This work described the physiography, soil material, and general soils of these states and their utilization, with especial reference to apples and peaches.

About 1920, the American Association of Soil Survey Workers, now the American Soil Survey Association, was formed. Thus, for the first time, those engaged in soil survey and classification were offered an opportunity to meet annually for discussion, and the presentation of papers. The annual reports of these meetings contain a valuable accumulation of scientific papers. It was in one of these (1922) that Marbut presented his genetic system for the classification of soils as applied to the United States. This work, patterned after the ideas of Glinka, marked a most important milestone in soil classification in the United States, and led to the extensive study of soil profiles in this country.

Soil surveys and classification now began to spread to other parts of the American Continent. In 1924 Bennett published a paper on "The Soils of Central America and Northern South America." In this were recorded observations on the characteristics and classification of soils in Costa Rica, Nicaragua, Colombia, Honduras, Guatemala, Salvador, and Ecuador. In 1926, Sweet issued a report on "The Soils of Haiti" giving locations, descriptions, and observations on soil utilization.

Whitson in the following year published a detailed report on "The Soils of Wisconsin," discussing the function of soils, climate, agriculture and forestry of the state and describing in detail the origin and classification of Wisconsin soils.

In 1927, the meetings in Washington, of the International Society of Soil Science produced many valuable contributions by Americans. Marbut presented "A Scheme for Soil Classification," an elaboration

on his previous paper. Shaw gave a paper entitled "The Basis of Classification and Key to the Soils of California," and Veach offered "The Classification of Organic Soils." In 1928 Bennett and Allison published the first comprehensive soil study and survey of any large area within the tropics utilizing modern methods of soil study and classification. It was entitled "The Soils of Cuba." In the same year, Marbut brought out the translation of Glinka's "The Great Soil Groups of the World and Their Development", a much-needed work heretofore unavailable in English. Shaw in 1930 reported on "The Soils of China" a preliminary field study of soil classification, climatic influences, origin and mode of soil formation, profiles and soil regions, in the eastern portion of this expansive country. In 1931 Lee contributed "The Possibilities of an International System for the Classification of Soils," in which, for the first time, the soils of areas in America and Europe are classified after the same system with an analysis of comparative results.

SOME EUROPEAN SOIL SURVEYS AND MAPS

No less interesting contribution on the subject have been made by workers in foreign countries, notably those in Russia. Difficulties of language proved a serious handicap in the world-wide distribution of their ideas and work, certainly until 1914 when Glinka (1916) published his "Die Typen Der Bodenbildung." Previously, however, in 1911, Hall and Russell reported upon "Agriculture and Soils of Kent, Surrey and Sussex" This work, generally considered throughout the British Empire as a classic of its time, gave the distribution of the soils, correlation between chemical and physical soil properties, crops and agricultural methods, and guidance to cropping and manuring of the various soil types. Many chemical and physical soil analyses were given.

Robinson published several interesting papers between 1917 and 1932, the most noteworthy of which appeared in 1930. It is entitled "A Method for the Classification of Soils for Purposes of Survey." In it he outlined a system of classification for the soils of Wales. This, the first European attempt to actually name soil types, marks a most important step in the progress of soil classification and survey abroad.

At the Soil Congress in 1927, Stremme presented "The General Soil Map of Europe," DeSigmond "The Classification of Alkali and Salty Soils," Wityn "A Brief Survey of Soil Investigations in Latvia," Zakharof "The Principal Soil Types of The Caucasus and Their Distribution," Saidel "A Soil Map of Roumania," and Prassolov "The Cartography of Soils or Soil Mapping"—all of which are outstanding contributions in their field. Krische in 1928, published "Bodenkarten" showing 77 maps and diagrams related to soil classification from all parts of the world. This is a most comprehensive work.

In 1929 Temple published "The Soils of Buckinghamshire" using approximately the same methods Hall and Russell previously had employed.

Brade-Birks and Furneux in 1930 published the first soil map in Europe, using the American method. Eleven soil series and 24 types are recognized and described.

In 1931 Robinson suggested detailed methods for surveying soils, in which it was pointed out that a system based on that used in the United States was the most desirable. The soil map of a survey of a district in Anglesea, utilizing this method, is shown.

SOIL CHEMISTRY

1. SOIL ACIDITY

The theory and methods of the measurement of the hydrogen-ion concentration as developed by Sörensen and by Clark and applied to the soil by Gillespie has enabled us to express, in terms of the pH value, one of the most important qualitative factors of a soil.

After the acidity of the soil had been accurately determined and defined, it was only natural that attention should be directed toward a study of the related quantitative factor. If the pH measured the intensity of the soil acidity, what then was the capacity of this acidity to neutralize bases? The quantitative side of soil acidity as expressed by the exchange acidity developed by a soil in solutions of neutral salts or acetates has been extensively studied by Kappen and has led to a more or less exact expression for the "lime requirement" of a soil.

2. BASE EXCHANGE

The most valuable contributions dealing with "base exchange" (cation exchange) have come from the work of Gedroiz and Hissink. Gedroiz was the first to recognize the influence of the nature of the exchangeable cations upon the properties of the soil and it was Hissink who defined the degree of saturation of a soil which he expressed by the ratio $S \times 100/T$ where S represents the exchangeable metal cations present in the soil and T the total exchange capacity.

3. SOIL COLLOIDS

The work of Ehrenberg and Wiegner must be looked upon as the most important contributions on the application of colloid chemistry to soil science. The comprehensive work of Ehrenberg was a great stimulus to the now rapidly advancing research in this fruitful field of study. The ionic hydration theory of Wiegner which satisfactorily accounts for the displacing power of the various cations is one of the many important contributions of this investigator.

The composition of soil colloids as determined by Robinson and Holmes is a fundamental work of great value in that it clearly shows the relationship between climate and weathering.

The work of Mattson who has established the amphoteric nature of soil colloids in relation to their composition has considerably advanced the science of soil chemistry. On the basis of the laws of isoelectric precipitation this investigator has presented a theory of isoelectric weathering.

SOIL MICROBIOLOGY

The period dating back 25 years marked a definite transition stage in soil microbiology. It seemed at that time that the most important groups of microorganisms concerned in the well-known soil biological processes had been discovered and described. It was believed that these processes were already well understood and their importance in plant nutrition sufficiently appreciated and correlated. As a result of the introduction of the solution culture methods by Remy and Lohnis, and of soil methods by Vogel, Lipman, and others, one felt that satisfactory methods had been developed for measuring the microbiological conditions of the soil just as one is able to measure the chemical condition. One was then tempted to conclude that it remained merely to work out the details of the procedures and investigations already well outlined. Lipman's "Bacteria in Relation to Country Life," which summarized the status of the subject of the microbial population of the soil and its importance in soil processes and plant growth, was published in 1908.

In 1910 there appeared Lohnis' monumental work, the "Handbuch der landwirtschaftlichen Bakteriologie," which tended to crown all the contributions to this subject and summarize not only what was known but also whatever was still to be known in the field of soil microbiology.

The appearance in 1909 and 1913 of the papers by Russell and Hutchinson on the rôle of protozoa in the phenomenon of partial sterilization of soil, the papers of Jensen, Goddard, and Waksman (1912–1916) on the fungi of the soil, the investigations of Krainsky (1914) on the actinomyces of the soil, of Melin and others on mycorrhiza fungi, opened new fields for the study of the microbial population of the soil.

In addition to these investigations of new groups of microbes, the bacteria themselves were not neglected. It is sufficient to call attention in this connection to the work of Hutchinson and Clayton on the aerobic cellulose-decomposing bacteria, of Khouvine on the anaerobic cellulose-decomposing bacteria, of Lipman, Waksman and associates on the sulfur-oxidizing bacteria, of Löhnis, Hänsen, Fred and associates, Stapp and others, on the specificity of legume bacteria, of Lohnis on the life cycle of Azotobacter and other bacteria, and of Christensen, Gainey and others on the influence of environmental conditions, such as reaction, upon the growth and activities of bacteria in the soil. The very methods used in soil microbiology have undergone marked modification. Of special interest in this connection is the appearance of the direct staining method of soil bacteria, introduced by Conn and developed extensively by Winogradsky. The return of this veteran investigator, whose contributions to the field of soil microbiology are second to none, marked in itself an important epoch. From 1922 to 1932 there appeared from his laboratory a number of contributions to our knowledge of soil bacteria and their importance in soil processes, which will in themselves tend to open new fields in this branch of science. The appearance in 1927 of Waksman's book, "Principles of Soil Micro-

biology," seemed to close this chapter in the history of the subject, just as Lohnis' book closed the previous chapter. However, the recent appearance of this book in a second edition, in a much altered state, points to the fact that the subject of soil microbiology is still undergoing very active change.

PLANT NUTRITION

Brenchley showed the necessity of certain mineral elements, as boron and manganese, in very minute quantities, for the growth of certain species of plants. These studies did much to stimulate investigational work on the mineral nutrition of plants. Blackman proved that practically all interchange of gases between the interior of the leaf and the atmosphere occurs through the stomata. He also applied the law of limiting factors to the interaction of the several factors governing any physiological process, as follows:—"When a process is conditioned as to its rapidity by a number of separate factors, the rate of the process is limited by the pace of the 'slowest' factor." Another Blackman suggested the application of the Compound Interest Law to the growth of an annual plant, and showed that in general the rate of increase in dry matter of a plant at any given time is directly proportional to the dry weight of the plant at that particular time. Brown, H. T., and F. Escombe made a classical study of the rate of diffusion of gases through a perforated plate, as related to the dimensions of the pores, and applied their results to the diffusion of CO_2 and water vapor through the stomata of the leaf. They also made the most extensive study yet made on the utilization of the available energy of the sunlight falling on green leaves, for the processes of photosynthesis and transpiration. Dixon advanced the cohesion theory to explain the ascent of sap in trees.

Garner and Allard stimulated research on photoperiodism of plants by their classical investigations on the effect of alternate periods of light and darkness (day and night) of varying length, on the growth and reproduction of different species and types of plants.

Kraus and Kraybill were among the first to establish clearly the influence of the carbohydrate-nitrogen ratio on the vegetative and reproductive phases of growth in plants, using the tomato as an experimental plant. This work has led to many other investigations of a similar nature, and has had considerable influence on modern agricultural practice, especially on fertilizing and pruning. Hoagland and his associates have contributed much useful data concerning the absorption of elements by plants.

Kostychev as a result of many and well-planned experiments on respiration proposed the theory that sugar is first attacked by the enzymes of fermentation, and that the end products of alcoholic fermentation are formed only in the case of weak oxidizing activity, such as is found in yeast and in the Mucoraceae. In the case of typically aerobic plants he believes that there are such large quantities of oxidizing enzymes present that the labile intermediate products of fermentation are oxidized before alcohol end products

can be formed. By using a new technique, an artificial interference in the process of fermentation, he was able to obtain an appreciable amount of the intermediate products of fermentation, products which indicated that ethyl alcohol formed in fermentation is formed by reduction from acetaldehyde, the latter being derived from pyroracemic acid. Thus for the first time was shown a direct connection between anaerobic and aerobic respiration in green plants. Maximov has made very significant contributions to the knowledge of the water economy of plants.

His book "The Plant in Relation to Water" is a critical and useful summary of progress in understanding the water relationships in plants. McHargue's work on the minor elements necessary for plant growth has been marked by careful experimentation necessary when dealing with elements present in such very small quantities. From his studies on manganese he has been led to believe that it is concerned in nitrogen assimilation and the synthesis of proteins. It is said to play the rôle of a necessary catalyst in plant metabolism and to function with iron in the synthesis of chlorophyll. Osterhout has done a great deal of work over a period of many years on the relation of electrical conductivity to changes in permeability. He has also contributed much data on the effect of different ions and combinations of ions on living processes. In agreement with Loeb, he explains the physical antagonism of salts in their joint effect on the protoplasmic surface which is thereby made impermeable, while the single salts easily penetrate and thereby bring about a toxic effect. Prianischnikov has devoted a great deal of his time to studies concerning the factors influencing ammonium and nitrate utilization in plants. He has noted the effects of physiologically acid or neutral or alkaline nitrogen-bearing salts, thereby advancing the knowledge of nitrogen absorption and assimilation. He has brought out the idea that ammonia is the primary product and at the same time the end product of the transformations of nitrogenous substances in the plant. Spoehr's work on photosynthesis and respiration has been characterized by careful experimentation based on sound chemical principles The useful data which he and his colleagues have accumulated can not be overlooked in any attempt to formulate a theory for the mechanism of the photosynthetic process. Eckerson's contributions deal mainly with the absorption and initial stages in transformation of nitrates to ammonium and amino acids in the plant. Mevius and Pirschle were among the first to do extensive and conclusive work on pH of the nutrient medium in relation to absorption of ammonium and nitrate. Tiedjens in a measure duplicated the work of Mevius and Pirschle but went further in that he studied not only absorption but elaboration or assimilation of ammonium and nitrate. Shive's research is especially notable. He determined the osmotic pressure of mixtures of nutrient salts and thereby worked out on a scientific basis feasible nutrient solution formulae.

Within the period of the existence of the American Society of Agronomy there have been some marked advances in the conceptions of soil fertility. There was at that time no particular coordination of

effort on the part of the specialists in science, and the agronomist was largely working alone endeavoring to handle the various scientific aspects of his problem, whereas now coordinated research among scientists is the rule rather than the exception, and agronomy has become itself a science and not merely an application of scientific principles taken from other sciences.

In the fertilizer industry with its important ramifications into chemical industry the changes are most marked. It was still rather largely an industry dealing with low grade materials of industrial wastes and poorly prepared chemicals and even the manufactured "acid phosphate" of that day cannot be compared with the modern product of the superphosphate factory of today. Now the industry stands rather firmly on the basis of being a chemical industry and scientific agronomy and practical farming deal with compounds of synthetic manufacture.

With the use of the new high analysis synthetic fertilizer products in agriculture have come new problems in the solution of which this Society is playing a leading part. Simultaneously with these meetings there is being held a joint meeting of a committee from this Society with committees from the fertilizer industry and machinery manufacturers to consider the experimental work on fertilizer placement and the changes necessary for safer and more profitable crop production. The machinery manufacturers are modifying their fertilizer distributing machinery to conform to these new agronomic practices with corn, cotton, beans, potatoes, and other crops.

In the matter of stopping the enormous nitrogen losses in soils the use of legumes and other crops as soil improvers has received in the last 25 years an enormous impetus through the introduction of new green manuring crops from remote countries to the lasting benefit of our agriculture and maintenance of our soil fertility.

In the development of methods for determining plant food requirements there has been an unusual period of activity in the last 10 to 15 years. I need only mention the exhaustive researches on the physiological and microbiological methods and the numerous ready chemical procedures for determining deficiencies in potash, phosphate, and nitrogen which have been brought forward and which no doubt will be helpful in the solution of the intricate problems of soil fertility and fertilization.

Within the 25 years of this Society the technique for conducting plat and field investigations has been very materially extended and improved and special committees of this Society have assisted very materially in this progress.

While absorption studies of plant nutrients by soils and their interactions with soil compounds form a chapter in early soil chemistry, the separation and study of soil colloids and their behavior, and the study of the so-called base exchange of soils has been a much investigated subject by soil scientists in late years. These investigations are aiding very materially in an understanding of the fundamental factors in soil formation and maintenance of soil fertility.

In the matter of soil acidity there has been noted progress and it has been one of the most prolific sources of soil and agronomic in-

vestigations. Twenty-five years ago it was a comparatively simple litmus paper test and all quantitative efforts were in the direction of lime requirement. Now it is a highly developed scientific study based on physical-chemical laws of hydrogen-ion concentration. The highly technical pH expression has become so familiar as the result of agronomic discussion and application that it even has meaning to the practical farmer in the consideration of his soil problems in the field. From lime requirement considerations it has risen to the rank of one of our fundamental factors in soil fertility matters as influencing the life of plants and microorganisms.

SOIL EROSION

The detailed and reconnoissance erosion surveys carried out by the Bureau of Chemistry and Soils have served to focus the attention of the entire nation upon the serious losses in soil destruction and land depreciation brought about by excessive washing of the soil. Many years ago the soil survey reports revealed the partial extent of these eroded areas, but it was not until 1929 that specific erosion surveys were undertaken. In that year a little less than $10,000 was expended by the Soil Survey for the purpose of studying the extent of the damage in the different regions of the United States. For the fiscal year 1930 the Congress appropriated the Bureau of Chemistry and Soils $160.000 for continuation of the erosion investigations. This initial appropriation was allotted as follows: Forest Service, $30,000; Chemistry and Soils, $65,000; Agricultural Engineering Division, Bureau of Public Roads, $65,000. The following year (1931) the amount was increased to $185,000. In the Appropriation Act for 1932 this appropriation was placed in the Secretary of Agriculture's miscellaneous items and the appropriation increased $330,000 of which $100,000 was allotted to the Forest Service and the remaining $230,000 divided equally between the Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering. As a result of the economy program the $230,000 allotted to the Bureau of Chemistry and Soils and the Bureau of Public Roads was cut to a net of $200,000, the sum of $30,000 going into the Secretary's savings.

During the past fiscal year eight erosion stations were in active operation and work on the ninth station was inaugurated at LaCrosse, Wisconsin. At the same time plans were completed and all preliminaries arranged for the inauguration of work on a tenth station located in Muskingum County, Ohio, on land purchased by the Ohio Experiment Station to be used exclusively for this work.

LYSIMETER INVESTIGATIONS

Among the many approaches made in unravelling the secrets of soil fertility none made a more general appeal than lysimetry. It promised to give an insight into the losses and distribution of the various soil constituents. And ever since the days of Dalton, who is credited with being the first one to install lysimiters, they were used by soil investigators throughout the world.

Within the last 25 years lysimeters have been installed in various

parts of the United States and abroad. Notable amongst them are the elaborate equipments at Cornell established in 1909 and 1910, at Florida in 1910 and 1911, at Texas in 1910, at Tennessee in 1911, at the New York (Geneva) Experiment Station in 1914, at Illinois in 1917, at Oregon in 1920, at Virginia in 1922, at Missouri in 1924, and at Connecticut in 1929. Mention should be made of the lysimeter installation at the Delaware Experiment Station, even though no description or even record of it could be found. The results apparently have not been encouraging as one might judge from the meager reports from the various stations. Outside of Cornell, Geneva, and Tennessee very few publications appeared. It is of interest to note that Cameron was very skeptical about the reliability of the results from lysimeter leachings.

The problem of leachings has been opened again with the installation of a new type of lysimeters at the New Jersey Station in 1929. These differ from the old type of lysimeters as they afford an opportunity to study the percolation of moisture through the undisturbed soil in the profile. The New Jersey installation has been duplicated by the Geneva Station for the study of fertilizer practices in orchard management. The first one to establish this new type of lysimeter was the Moscow Agricultural Experiment Station in 1919.

On the European continent very few new lysimeter installations have been made for the last 25 years. Even the reports on the older installations are meager. We have data reported on lysimeters at Bromberg, Germany, and in Sweden. A new installation was made in 1918–1920 in Scotland, in the U. S. S. R. at Mleev and at Moscow where the new type of lysimeters has been installed.

FIELD PLATS

The Morrow plats at Urbana, Illinois, were established in 1876. They were given official recognition three years later. These are the oldest soil plats in America. The Davenport plats at the same institution were established about 1896. Other field plats at this institution have been established at various times since.

In 1924, 34 fields aside from those at Urbana were in operation.

The Jordan fertility plats at Pennsylvania State College were established by W. H. Jordan in 1881. Other series of plats have been established since that date.

The New Jersey field plats for the study of lime requirement and nitrogen availability were established in 1908.

The oldest continuous experimental plat at the Tennessee Station dates back to 1905. One series of 25 plats has been used continuously in a soil fertility study in a rotation of cowpeas and wheat.

In another series of 15 plats, the effects of manuring and liming have been studied in a 4-year rotation of corn followed by crimson clover, cover crop, soybeans, wheat, clover and grass.

The men most closely related to this work are C. A. Mooers, J. E. Converse, C. R. Spangler and H. P. Ogden, assistants in the conduct of the field work. The following chemists made most of the nitrogen and humus determinations: H. H. Hampton, W. K. Hunter, L. G. Willis, Dr. W. H. MacIntire, and J. B. Young.

The Massachusetts plats were established in 1889 by Dr. W. P. Brook for the study of the effects of a continued use of fertilizer containing a single plant food, for the study of fertilizers for corn, tobacco, onions, comparative value of nitrogen carriers, etc. Contributors were Haskel, Jones, Beaumont, and Snell.

Within the 25 years of this Society rapid progress has been made in strengthening the research organizations and facilities. New institutions, like the Boyce-Thompson in the U. S., the International Institute of Agriculture in Rome, etc., new chairs and foundations, like the Frasch, etc., new Journals, new societies, have been founded, all dedicated to one great aim—to expand our knowledge of soils and of agricultural science as a whole.

A QUARTER CENTURY OF PROGRESS IN THE DEVELOPMENT OF PLANT SCIENCE[1]

C. W. WARBURTON[2]

It was with some hesitation that I accepted the invitation to discuss the progress of the past 25 years in plant science at this anniversary meeting of the American Society of Agronomy. This is rather a heavy assignment to one who has for nearly 10 years been outside the agronomic field. Perhaps, however, an outsider looking in can view the field with a less prejudiced eye than one who is on the inside. What I have to say is based very largely on suggestions which have been generously supplied to me by specialists in the various fields of crop production, to whom I express my sincere appreciation. Lack of time prevents the use of much of the very interesting material submitted to me by agronomists and plant pathologists Interest in advances in plant science is as broad as the membership of this Society, covering not only the production and introduction of new crops and varieties and studies of new methods of technic in production, but the contributions of our fellow scientists in the fields of entomology and plant pathology, whose discoveries in methods of controlling insects and plant diseases are to a large extent translated into action by agronomists. I shall be compelled, however, to confine myself for the most part to advances in plant science with which agronomists have been principally concerned.

The 25-year period covered by the life of the American Society of Agronomy has been a varied and interesting one. Beginning with a slight financial flurry in 1907, the first 7 years in the Society's history were fairly quiet and profitable ones for agriculture. The European war in 1914 cut off to a considerable extent our market for wheat, cotton, and other farm products, while our entrance into the war in 1917 brought new problems to the agronomists, particularly those

[1]Presented as part of the special program commemorating the twenty-fifth anniversary of the American Society of Agronomy, Washington, D. C., November 17, 1932.
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involved in the greatly increased production of wheat and other food crops demanded by our allies and by our own armed forces, which demands had to be met with greatly reduced man power on our farms. We all remember the slogan, "Food Will Win The War," and the energy with which experiment station and extension workers entered into plans to increase food production. The high prices during the latter part of the war period of course were an important factor in helping to carry out the patriotic urge for the largest possible production of wheat and other foodstuffs. High prices for crops and livestock led to inflation of all agricultural values, which war-time prosperity of the farmer lasted for somewhat more than a year after the war, during which time we were feeding and clothing Europe at high prices and loaning Europe the money with which to pay us. This kind of prosperity could not last and for the past 10 years or more the farmers of the country have been trying to get over the headache for which the agronomists, economists, and all the other "ists" have not yet found a very satisfactory remedy.

In the following pages, I will attempt to call the roll of some of the principal changes in crop production which have taken place in the 25 years since the American Society of Agronomy was organized. I can not hope to name them all, and I trust my hearers who may happen to be the proponents of any new variety or method I fail to mention will understand that such failure is due to lack of time rather than to my failure to appreciate their activities.

CORN

Twenty-five years ago breeders and growers of corn were just beginning to wonder whether there was any real connection between the show type of ear which won prizes at exhibitions and performance in the field. About that time, also, we began to realize the limitations of ear-to-row breeding. Agronomists and plant breeders were seeking some other method of corn improvement which would give more certain results. The first report on experiments involving selection in self-fertilized lines of corn was made in 1908. The progress that has been made in the isolation of self-fertilized lines and their combination in high-producing hybrids lies wholly within the past 25 years. While the commercial utilization of this method of corn improvement is not yet general, the possibility of producing yields far in excess of those commonly grown has been successfully demonstrated.

The very comprehensive series of studies of corn diseases conducted by the Bureau of Plant Industry in cooperation with the corn belt experiment stations and corn breeders had not been started 25 years ago. The importance of that group of diseases known as ear, stalk, and root rots and their effect on germination, growth, and production has been fully demonstrated by the pathologists, and pathologists and agronomists have joined in the selection of new strains resistant to these diseases. The effect of the presence or absence of certain minerals in the soil on the development of these diseases and on the production of the corn crop has been recognized.

Although experiments in New York and Illinois long before 1907 had shown that the primary function of tillage was to keep down

weeds rather than to control the moisture supply, these findings had gone unnoticed until they were verified by later work. Limiting the cultivation of corn to processes necessary for weed control frequently has a material effect on the cost of production. Experiments in the hill application of fertilizers have shown much greater efficiency from this method than from the use of the same quantity of fertilizer applied broadcast. Fertilizers applied in the hill have also promoted early maturity and consequent soundness of the crop

WHEAT

The past 25 years have been a period of progress in the production and distribution of new wheat varieties At least one-third of the total wheat acreage of the United States is now sown to varieties introduced from foreign countries or produced by the Department of Agriculture or state experiment stations since 1907. In addition, Durum wheat, which was introduced and popularized by the Department shortly before 1907, is grown on several million acres The outstanding variety of wheat in the United States in recent years has been Marquis, produced by Canadian plant breeders and introduced into the United States about 1912 Its early maturity enabled it to escape to a large degree from injury by stem rust which took heavy toll from the varieties of spring wheat formerly grown in our northwestern states. This characteristic, as well as its high milling quality, was quickly recognized by American farmers and within a few years after its introduction it was very generally grown. It is estimated that in 1929 this variety was grown on 12 million acres. Within the last few years it has been giving way to Ceres, a new and more rust-resistant variety produced by the North Dakota Experiment Station, of which it is estimated that 4 million acres were grown this year. Other hard red spring wheats introduced in recent years include Progress, Red Bobs, Kota, and Marquillo.

About 1916, the Kansas Agricultural Experiment Station began the distribution of a pure-line selection of hard red winter wheat which it called Kanred. This variety is fully equal to Turkey and other hard red winter wheats in milling and baking qualities and in many sections it outyields the older strains. It is now grown on about 4 million acres a year. Several other experiment stations have put out strains of hard red winter wheat, among which may be mentioned Iobred, Karmont, Michikof, Montana No. 36, Nebraska No. 60, and Newturk. The Washington Experiment Station has given particular attention to the development of varieties of wheat resistant to bunt, as ordinary methods of bunt prevention are ineffective in the Pacific Northwest. One of their bunt-resistant varieties, Ridit, is quite extensively grown. Experiment stations in soft red winter wheat areas have also been active in producing new varieties, Trumbull, a production of the Ohio Station, being grown on about 1 million acres annually. Other varieties which have attained local importance are Red Rock from the Michigan Station, Nittany from Pennsylvania, Fulhio from Ohio, and Forward from New York. Advantage has also been taken of the work of wheat

breeders in other countries, Federation wheat from Australia, introduced by the Department, now being grown on nearly 1 million acres in our western states.

In wheat production an important work done by agronomists has been the exposure of frauds which promoters have tried to foist on the public at high prices. Within the 25-year period efforts have been made to promote the sale of the frequently recurrent seven-headed wheat, its most recent promotion being under the name of Alaska. A fairly good old variety of wheat was for a time offered at high prices under the name of Miracle, the principal promoter being an evangelist who predicted a 7-year famine from which buyers of Miracle wheat would be saved because of the alleged high yield characteristic of this variety. The actual merits of Alaska and Miracle wheats were determined through careful experiments by agronomists and publication of the results no doubt saved many dollars to American farmers.

Much progress has been made since 1907 in determination of the best rates, dates, depths and methods of seeding wheat and other grains. The furrow method of wheat growing in the Great Plains has resulted in reducing losses from winterkilling and soil blowing in Montana, eastern Wyoming, and northeastern Colorado.

Discovery by pathologists of physiologic races of cereal rusts and smuts has materially affected the work of the agronomists and plant breeders. Breeding for disease resistance has received great impetus as it is now possible greatly to refine our methods of determination of the resistance of a variety or strain to cereal rusts and smuts. The recognition of physiologic races of cereal rusts and smuts is probably one of the most important events of the last 25 years which have influenced crop production.

OATS AND BARLEY

Very material changes have been made in oat production in the past 25 years, principally through the introduction of an early variety from the Kherson district of southern Russia. This was first introduced as Kherson by the Nebraska Experiment Station and a little later under the name Sixty-day by the federal Department of Agriculture. This variety had become quite popular in the corn belt and the northern great plains 25 years ago, about which time several of the corn belt experiment stations began efforts to improve it through pure-line selection, the most important of which are Richland, Iowar, and Iogold put out by the Iowa station, although Nebraska, Minnesota, and Wisconsin also introduced pure-line strains from this original stock. Later-maturing varieties produced by the experiment stations include Cornellian, Ithacan, and Upright from New York; Keystone and Patterson from Pennsylvania; Miami and Franklin from Ohio; Wolverine and Worthy from Michigan; Wisconsin Wonder from Wisconsin; and Minota from Minnesota. Several strains resistant to stem rust or escaping stem rust because of their earliness have been of value where epidemics of this disease are frequent. Markton from the Moro substation in Oregon shows high

resistance to smut. The combination of some of these disease-resistant strains, including Australian varieties resistant to crown rust, with some of our high-yielding non-resistant strains by hybridization is now under way with promising strains in process of segregation.

The 18th amendment and the Volstead Act presumably had a serious effect on barley production. As a matter of fact, however, the acreage of barley has increased greatly in recent years and even in pre-Volstead days not more than 25 or 30% of our barley crop was used for malting. Varieties of barley introduced within the last 25 years now make up an important part of our production, particularly Trebi which was first grown at the University of Minnesota in 1907 as a pure line from an importation from Asiatic Turkey. It first came into prominence as a variety grown under irrigation in Idaho but has gradually spread over the semi-arid and even into the humid sections Varieties of north African origin grown in the Pacific states include Coast, Club Mariout, and California Mariout. A promising pure-line selection of Coast which is finding favor is called Atlas. From the standpoint of the farmer, and particularly the farmer boy who had unpleasant experience in handling the old rough-awned barleys, the most important recent improvement is the production of smooth-awned varieties The first of these resulted from hybridizing a smooth-awned variety of little agronomic value, Lion, and some of the better commercial varieties. Among the smooth-awned strains now being grown commercially are Velvet, Glabron, Wisconsin Pedigree Nos 37 and 38, and Spartan.

OTHER GRAIN CROPS

The most important happening in rice production is the introduction of this crop into California where, following experiments conducted by the Bureau of Plant Industry and the California Experiment Station beginning in 1909, commercial production developed rapidly to more than 100,000 acres a year. Practically the entire acreage of rice in California consists of the Caloro and Colusa varieties, both produced at the Biggs Rice Field Station. In the South, 65,000 acres are now sown to varieties of rice produced by the experiment stations or recent introductions by the Department.

The important grain sorghum crop of the southern great plains is based almost entirely on varieties introduced by the Department of Agriculture, most of which, however, were already in cultivation in 1907 The introductions of the past 25 years include Dwarf Hegari and Feterita. The Texas, Oklahoma, and Kansas experiment stations and the Department have been active in producing new and improved strains of the grain sorghums and in distributing pure seed of those which originated from other sources. Dawn and Sunrise kafirs were among the early strains of white kafir which attained some popularity. Beaver milo, a dwarf, erect milo suitable for machine harvesting, was developed at the Woodward, Okla., Station from a back cross of dwarf yellow milo on a kafir-milo hybrid. Wheatland milo, selected from a kafir-milo hybrid and also adapted to machine harvesting, is being grown to some extent in Kansas and Oklahoma Atlas sorgo, produced by the Kansas Station, is a tall, stiff-stalked,

leafy sweet variety with white seeds acceptable as kafir on the market. Probably more progress is being made in the production of valuable strains of grain sorghum through hybridization than of any other grain crop. The ease with which hybrids are produced and the wide variety of forms resulting from hybridization lends this crop to exploitation and an important part of the work of the agronomist in the southern great plains has been to check by careful experiments the extravagant claims made by producers of grohoma, shallu, schribar corn, and others.

Efforts to improve flax have to a large extent been devoted to the production of disease-resistant varieties, in which leadership has been taken by the North Dakota Station. The earlier strains were not named but were given N. D. R. (North Dakota resistant) numbers. These have to a considerable extent been replaced in recent years by Bison, a selection from the North Dakota Station, and Redwing, developed at the Minnesota Station. The Minnesota Station, finding that certain varieties were immune to rust, has combined rust immunity with wilt resistance through crossing these varieties with some of the wilt-resistant strains. Experiments have shown the desirability of early seeding and of seeding at heavier rates than were commonly practiced.

ALFALFA

In the field of forage-crop production very material progress has been made during the past 25 years. Careful experiments in adaptation of varieties and strains conducted cooperatively by the Department and several of the state experiment stations have shown the range of adaptability of the various types of alfalfa. It has been shown that common alfalfa from the southwestern states, while not sufficiently cold resistant for growing in the North, grows more rapidly in the South and is more productive there than the northern forms.

For many years, long-established stands of alfalfa in the non-irrigated sections of Nebraska, Kansas, and Oklahoma have been failing for reasons not well understood until the Nebraska Station determined that these failures were due to exhaustion of sub-soil moisture. The deep penetration of alfalfa roots enabled this crop to draw on moisture supplies at greater depths than other crops, but when these supplies were exhausted they were not replenished by ordinary rainfall. The remedy seems to be to abandon attempts to retain alfalfa stands for extended periods in this area, but instead to treat it as a short-time crop dependent on annual rainfall. With the present low price of alfalfa seed this method of handling the crop is practical.

Progress is being made in the development of strains resistant to alfalfa wilt, to which Ladak, a comparatively recent introduction by the Department of the Turkestan group, is quite resistant. The growing of alfalfa in short rotation is becoming more common in the eastern states where it is difficult to maintain a satisfactory stand over a long period. With alfalfa and clover seed selling at about the same price, alfalfa is to some extent replacing red clover.

SOYBEANS

Although soybeans were known in the United States for more than 100 years prior to 1907, they were grown on only about 150,000 acres at that time. Since then, the planting of this crop has very greatly increased, the area devoted to it now being about 3½ million acres. The 1¼ million acres harvested for seed last year produced nearly 19,000,000 bushels of soybeans. Twenty years ago, mills for the extraction of oil from soybeans were unknown in this country, while now at least 12 are engaged in the manufacture of soybean oil and meal. Numerous products are being manufactured from the meal and oil, the number in this country being estimated as high as 150 by W. J. Morse.

The soybean is extremely variable in size and color of seeds, habit of growth, period of growth, oil and protein content of seed, and other characteristics Numerous varieties have been introduced from Japan, Chosen, and Manchuria and have been widely tested in an effort to find those that are best adapted to different sections of the country. The Department is attempting to produce varieties adapted to different sections which will give similar results in the hands of manufacturers

OTHER FORAGE CROPS

Lespedeza was commonly grown in the South for many years, but little attention was paid to it until about 20 years ago. In 1912, Professor Essary of the University of Tennessee began to study lespedeza varieties, one of which he introduced as Tennessee No. 76. In 1919, the Department introduced Korean lespedeza which seems to be especially suited to the states from Virginia and North Carolina westward The first distribution of 240 pounds of seed was made by the Department in 1921, while sales of seed in 1931 amounted to 8 million pounds in addition to which large quantities were harvested and used by farmers on their own farms Korean and other varieties of lespedeza bid fair to work a real revolution in the poor lands of the South. These acid-tolerant legumes furnish excellent yields of hay and pasture and improve the productiveness of the soil to a remarkable extent.

Twenty-five years ago sweet clover was regarded as a common weed of no commercial importance. The wide use of this plant as a pasture and soil improvement crop in the corn belt has come since 1907. This is an illustration of how a plant may be neglected for many years and suddenly spring into wide popularity. It now ranks high up in the scale of useful legumes.

Another forage crop unknown 25 years ago but now widely grown throughout the southern and central states is Sudan grass, introduced from the Sudan region of Africa in 1909. This new annual forage grass found instant favor and within a period of a few years was very widely grown. You will recall that this grass was introduced as the result of the belief of C. V. Piper that there must be somewhere in Africa an annual sorghum with the growth habits of Johnson grass but without its troublesome perennial root stocks. Piper believed

that search would reveal such a plant and that, if found, it would prove widely useful in the United States. His reasoning proved to be entirely correct, this annual forage sorghum coming from the Sudan as the result of the search instigated by him.

COTTON

The past 25 years have seen the introduction and distribution of a large number of new varieties of cotton by the Department, the state experiment stations, and private breeders. Some of these, such as Acala, have attained wide prominence, while others have been quite localized in their distribution. Notwithstanding the large number of new varieties introduced in recent years and the efforts that have been made by plant breeders, agronomists, and farmers to improve the cotton crop, it is generally recognized that little actual progress has been made when the crop as a whole is taken into consideration. This condition is due principally to the freedom with which cotton cross fertilizes, resulting in mixture of varieties in adjacent fields, the mixture of seed in commercial gins, and the general use by farmers of gin-run seed. With all these facilities for the mixing of varieties there is little wonder that there has been no greater progress in the improvement of the cotton crop.

The Department, the experiment stations, and extension services of the southern states and the American Cotton Cooperative Association have been interested in solving this problem through the establishment of single variety communities. By agreement, all farmers in such a community grow one variety of cotton, the seed of which is obtained originally from a common source. This cotton is all ginned at the community gin which gins no cotton from outside the community, thus preventing mixture of varieties in ginning. The growing of a single variety in a community not only insures the maintenance of its purity and therefore the production of cotton of uniform length and strength of staple, but also is an aid to marketing in that dealers are able to buy in quantity in the community the type of cotton they need.

With the spread of the boll weevil over the cotton belt the necessity for early maturity of cotton to escape weevil injury is greatly increased. Most of the early varieties of cotton produce short inferior staple. The desirable practice, therefore, is to grow the longer staple varieties in such a way as to obtain the maximum production of bolls early in the season. Bolls are produced only on the small fruiting branches which develop from the main stalk and from the side stalks or vegetative branches. When the plants are far enough apart for the development of these side stalks the setting of bolls must be delayed until these stalks are sufficiently developed to produce fruiting branches. Close spacing in the row, therefore, which practically eliminates the development of side stalks and confines the production of bolls to fruiting branches borne on the main stalks hastens the maturity of the crop and aids materially in escaping weevil injury. This closer spacing is one of the principal changes which has taken place in cotton production in recent years.

As in cereals and forage crops, progress has been made in breeding cotton resistant to some of the important diseases, particularly cotton wilt, which disease is widely distributed, particularly on sandy soils in the southeastern states and the Mississippi Valley. Breeding of wilt-resistant strains is largely the accomplishment of the last 25 years.

OTHER FIBER CROPS

Agronomists and plant breeders have worked to a limited extent with minor fiber crops, particularly hemp and fiber flax. These crops are not grown extensively in the United States, although there has been some increase in fiber flax production in recent years, particularly in Michigan and Oregon. The first systematic work in breeding hemp was started in 1914, since which time numerous crosses have been made between strains from different countries. There is a wide variation in height, earliness, uniformity, and fiber production, with excellent opportunity for improvement through selection. A strain 3 weeks earlier than the standard hemp has been distributed in Wisconsin.

SUGAR PLANTS

Improvement in sugar cane varieties by breeding is to a large extent the accomplishment of the last 25 years, although the fact that sugar cane produces viable seed was discovered somewhat earlier. The Dutch in the East Indies did some of the earliest and best work in sugar cane improvement and we are indebted to them for most of the varieties used successfully to combat the ravages of mosaic disease in Louisiana. One of these Dutch varieties, P. O. J. 2878, bred in 1921, proved so superior that 12½% of the total cane area in Java was planted to it in 1927 and 93% in 1929. The growing season in Louisiana is not long enough to permit the use of this variety, but other strains bred at the Java station have been very successful there. The mosaic disease and other troubles so affected Louisiana sugar-cane production that only 47,000 tons of sugar were produced from 128,000 acres of cane in 1926. Several mosaic-tolerant varieties had been introduced into Louisiana by the Department in 1924 and by 1929 the culture of these had become general enough so that 200,000 tons of sugar were produced. These and other varieties since introduced have assisted in the restoration of production in Louisiana to the extent of 300,000 tons or more annually. One of the varieties now being used, C. P. 807, was produced by the Department at its station at Canal Point, Florida. This variety is especially adapted to heavy, poorly drained soils on which other strains have not given satisfactory yields.

Until recent years the United States has been dependent on Europe for its supply of sugar beet seed. The various strains of sugar beets produced by European breeders were selected for increased yield of beets and increased sugar content, but none of these strains have any appreciable resistance to curly top or leaf spot, two diseases which cause heavy losses in the United States. In recent years efforts in this country have been directed toward the breeding of varieties

resistant to these diseases and considerable success has been attained, although the resistant strains are not yet available for commercial culture. The development of varieties resistant to curly top will not only increase yields in the areas where sugar beets are now grown but make possible the commercial culture of this crop in other areas where it has practically been inhibited by this disease.

TOBACCO

Material improvement has been made in tobacco varieties, particularly in the quality of the product. Several strains of cigar filler leaf with low nicotine content have been produced to meet the popular demand for a mild cigar. For instance, a new strain of Cuban tobacco normally contains not more than one-third of the nicotine content of the parent type. Maryland Mammoth is a very vigorous and productive variety which is of special interest because the study of this variety led Garner and Allard to their very important discoveries on the effect of length of day on plant growth and maturity. Maryland Mammoth, while producing large yields of tobacco in Maryland, will not mature seed there. It does, however, produce seed freely under the short-day conditions found in Florida.

Much progress has been made in breeding tobacco varieties resistant to several important diseases. The discovery by Allard in 1914 of the rôle played by insects in transmission of tobacco mosaic led to similar discoveries of insect relationship to the transmission of many virus diseases of plants. Strains resistant to mosaic have been developed and also strains resistant to root rot. Methods of seed-bed sanitation have been effective in controlling several of the diseases affecting seedling tobacco plants.

The texture, flavor, and burning qualities of tobacco are affected by many factors, such as the nature of the soil on which the crop is grown, its mineral constituents, the fertilizers used on the crop, and the effect of preceding crops. Not only is the quality of tobacco affected by the availability or deficiency of important plant food elements, but different forms of fertilizer containing the same fertilizing constituents from a chemical standpoint have widely different effects on tobacco production Important progress has been made in recent years in studying the tobacco plant and in determining the conditions necessary for the production of tobacco of any particular type or quality. On some soils continuous cultivation of tobacco is more successful than the usual type of rotation which includes soil improvement crops.

EXTENSION WORK IN AGRONOMY

The history of the American Society of Agronomy is practically coincident with that of the Extension Service. Extension work was started a few years before the American Society of Agronomy was founded, but the first county agents were being appointed about 1907. Without the help of the extension forces it would not have been possible for research workers to have their work translated into action by farmers anywhere near as promptly as has been done in the

last 25 years. Extension agronomists and county agents have been important factors in inducing farmers to grow new crops and new varieties, to adopt new methods of cultivation and fertilization, to use soil improvement crops, to terrace their lands, and to take other actions recommended by research workers of the Department of Agriculture and the state experiment stations. The 80 or more extension agronomists employed by the several states and the 2,800 county agricultural agents and assistant agents are a factor for translating research into action which was practically unknown 25 years ago.

An important activity which has been fostered very largely by extension agronomists and county agents is the organization and conduct of state pure seed associations. The members of these associations have been interested not only in trying new and improved varieties but have provided a reliable source through which the products of the experiment stations could be made available to the general public. Many illustrations of the effectiveness of these associations could be given, but most of you are familiar with what they have done in your own states and there appears to be no need to go into detail regarding them. The rapid spread of new varieties of wheat, oats, barley, or other cereals, of soybeans and of Korean lespedeza, are illustrations of what has been done through the extension forces and the state pure seed associations.

Extension agronomists and county agents have been important factors in promoting more efficient production of both crops and livestock through the increase of leguminous forage crops. Recent increases in the acreage of alfalfa in the eastern half of the United States and of sweet clover, soybeans, and lespedeza, are to a very considerable extent due to the interest taken in these crops and the campaigns for their production promoted by extension workers. In the South, extension agents have been active in promoting the use of winter cover crops, such as vetch and Austrian peas. All of these crops provide sources of cheap nitrogen, improve the physical condition of the soil, and increase yields of succeeding crops at low cost.

Another way in which the livestock industry has been aided by the agronomists and extension workers, particularly in the eastern and southern states, is through the improvement of pastures. Two of the most important farm problems were long neglected by research workers and by farmers themselves. These are the problems of pasture improvement and weed control. Recent years have shown material progress in both of these fields. In the northeastern states and in the hilly sections of Ohio, Indiana, and West Virginia considerable progress has been made in the renovation of old pastures through re-seeding and fertilization. In the South the interest of extension workers in permanent pastures is beginning to bear fruit, particularly since the introduction of improved varieties of lespedeza.

This paper is supposed to be confined to advances in plant science, leaving discussion of soil science to the address of Director Lipman. I cannot refrain, however, from mentioning the effective work which has been done by extension workers (1) in promoting the use of green manures, (2) in fertilizer standardization, (3) in developing sources of

lime and making it easy both for the farmer to determine the need of his land for lime and to obtain his supply of lime at moderate cost, and (4) in promoting the use of terraces for the conservation of soil and moisture.

IN MEMORIAM

No review of the happenings of the past 25 years in plant science would be complete without pausing for a moment to pay tribute to those who have played an important part in plant production and in the work of this Society and who are no longer with us. Mark A. Carleton, prime mover in the organization of the American Society of Agronomy and its first president, cerealist and pathologist, introducer of durum wheat and many strains of hard red winter wheat, oats, and other cereals; W. J. Spillman, plant breeder, re-discoverer of Mendel's law, pioneer worker in farm management, whose catholicity of interest covered all phases of agriculture; E. C. Chilcott, organizer and director of the most complete series of experiments in crop rotation and studies in dry land agriculture ever devised; C. V. Piper, botanist, entomologist, and agronomist, a fearless but kindly and constructive critic, president of this Society, and for many years a member of its editorial board; and Piper's long-time associate, R. A. Oakley, one of the bravest and friendliest souls any of us has ever known. These and others who had a part in the organization of the American Society of Agronomy or who have been important factors in its progress and in the advances which have been made in the field of plant science have completed their labors, but their work will carry on. We do honor to ourselves in honoring them.

GENETICS OF THE SOYBEAN[1]

C. M. Woodworth[2]

PRESENT STATUS

Considerable progress has been made in the genetic analysis of the soybean. The behavior in inheritance of more than a score of characters has been worked out. Most of these are so-called qualitative characters, such as seed color or flower color, that are probably of indifferent value so far as productivity or performance is concerned. Nevertheless, a knowledge of the mode of inheritance of these characters is of distinct aid to the breeder.

Numerous types of soybeans exist differing in obvious characters of the seed and plant; and the more one works with this crop the more types are discovered. It would seem that with such abundant genetic material available, more should be known at the present time about the genetics of the soybean Probably the difficulty in making

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Station. Also presented at the annual meeting of the Society held in Chicago, Ill., November 19, 1931. Received for publication March 12, 1932.
[2]Chief in Plant Genetics.
[3]Ref erence by number is to "Literature Cited," p. 50.

crosses has deterred many people from choosing this plant for their genetic studies. At any rate, if the writer is correctly informed, comparatively few geneticists are now devoting any considerable time to the soybean.

In a recent study of available literature, the attempt was made to bring together the results of genetic studies on the soybean and to make an up-to-date list of genes which have been reported. The author has taken the liberty to assign symbols to certain characters which had been investigated, but not named, by other workers, and also to change slightly certain other symbols in order to bring them into line with current usage. The following is the list of genes arranged in alphabetical order.

LIST OF GENES IN SOYBEANS ARRANGED IN ALPHABETICAL ORDER

B_1, B_2, B_3, genes for "bloom" on seed coat.

D_1, one of duplicate genes for yellow cotyledons; d_1, green cotyledons.

D_2, one of duplicate genes for yellow cotyledons; d_2, green cotyledons.

De, normal seed coat; *de*, defective seed coat.

Df, normal; *df*, dwarf type.

Dt, indeterminate; *dt*, determinate.

E, early maturity; *e*, late maturity

F, normal stem development; *f*, fasciated or flattened stem

G, green seed coat; *g*, yellow seed coat.

I, i^i, i^k, i, multiple allelomorphic series for inhibition of black and brown pigment in seed coat.

- I, total inhibition; seeds show no black or brown pigment even in hilum; identical with I^h.
- i^i, partial inhibition; permits pigment only in hilum; identical with I^i.
- i^k, partial inhibition; responsible for Black Eyebrow pattern; identical with I^k.
- i, no inhibition; seeds are entirely black or brown.

L, dark-colored or black pods; *l*, light-colored pods.

M, responsible for black mottling on a self-brown seed coat; *m*, no mottling.

N, gene for normal hilum such as is found in most soybean varieties; *n*, abnormal hilum such as is found in the Soysota variety.

Na, broad leaflet of most varieties; *na*, narrow leaflet.

P_1, inhibition of pubescence, causing glabrousness; p_1, no inhibition.

P_2, gene for pubescence; p_2, no pubescence.

R_1, r_1, r_1^o, multiple allelomorphic series for seed coat color.

- R_1, complimentary with R_2 for black seed coat or hilum.
- r_1, complementary with R_2 for brown seed coat or hilum; recessive to R_1.
- r_1^o, complementary with R_2 for reddish brown seed coat; recessive to R_1 and r_1.

R_2, complementary with R_1 for black seed coat or hilum; r_2, recessive to R_2.

S, tall, late-maturing type; *s*, stocky, early-maturing type.
St, normal production of seed; *st*, sterility.
T, tawny or brown pubescence color; *t*, gray pubescence color.
V_1, normal chlorophyll development; v_1, variegation.
W, purple flower color; *w*, white flower color.
X, extra leaflets in compound leaf; *x*, normal number, *three*.

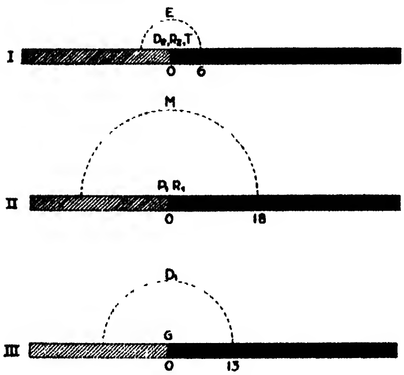

FIG. 1.—Chromosome chart showing the three groups of linked genes that have been worked out thus far in the soybean.

CHROMOSOME MAP

Only three groups of linked genes have been established for the soy bean thus far, and there are only two loci in each group. A provisional chromosome map is presented in Fig. 1.

The method (somewhat modified) of representing the genes as being on one or the other side of a fixed locus is borrowed from Emerson and his co-workers, who have used it in their progress reports on the genetics of maize.

In group I, genes *De*, R_2, and *T* are located at O, since they have shown complete linkage in cross-breeding experiments, and according to Owen (5),[3] *E* is 6 units away. In group II, P_1 and R_1 are located at O, since they also appear to be completely linked, and *M* is 18 units away. Finally, in group III, *G* is considered to be at the O point, with D_1 13 units distant to one side or the other.

According to Karpentschenko (4), there are 20 pairs of chromosomes in the soybean. There should be, therefore, 20 independent groups of genes. Of these, only the three described above have thus far been established in a preliminary way, leaving 17 yet to be worked out. Many other genes have been studied, but they have been found to be independent of groups I to III and of one another. Hence, while considerable progress has been made in a study of the genetics of the soybean, much remains to be done.

NEW QUALITATIVE CHARACTERS

Data will now be presented on the inheritance of a few new characters, the genes for which were included in the above list.

BLOOM ON SEED COAT

A bloom or waxy covering occurs on the seed coat of certain types of soybeans, as for example, Sooty and the Wild soybean (*Soja ussuriensis*). Evidence on the inheritance of this character is furnished by two crosses and is presented in Table 1.

The evidence indicates that bloom on the seed coat is determined by three genes, B_1, B_2, B_3, all of which are necessary to produce the character. If this interpretation is correct, Sooty carries all three

TABLE 1.—*Inheritance of bloom on seed coat*

Cross No.	Parents	Character of parents	Character of F_1	F_2 data						Dev. P E.
				Observed results		Expected results		Expected ratio		
				Bloom	No bloom	Bloom	No bloom	Bloom	No bloom	
1	Manchu x Sooty	No bloom Bloom	Bloom	243	78	241	80	3	1	.38
2	Dunfield x S. P. I. 65388	No bloom No bloom	Bloom	119	155	116	158	27	37	55

genes and Manchu only two. Also, in the cross Dunfield X S. P. I. 65388, one parent must carry two of these genes and the other parent the third gene. A study of F_3 plants grown the past season should indicate whether the above is the correct interpretation.

F_2 data from the above crosses show that bloom is independent in inheritance of the gene pairs *Ww*, *Tt*, *Ii*, *Ll*, and probably of R_1r_1 and $R_2\,r_2$.

VARIEGATED LEAF

Leaf variegation (v_1) is a new character which arose in our material presumably as a mutation. The original plant was discovered in an F_3 family of a natural hybrid. Neither parent exhibited the character. The progeny of the mutant bred true for variegation. Crosses were made with Elton and with the recessive glabrous type discovered by Stewart and Wentz (6). Results are given in Table 2

TABLE 2.—*Inheritance of variegation*

Cross No	Parents	Character of F_1	F_2 data: Observed results V_1	F_2 data: Observed results v_1	F_2 data: Expected results V_1	F_2 data: Expected results v_1	F_2 data: Expected ratio V_1	F_2 data: Expected ratio v_1	Dev./P.E.
43	Elton x Variegated	Normal	123	49	129	43	3	1	1.56
44	Variegated x Recessive glabrous	Normal	129	20	112	37	3	1	2 45
46	Variegated x Recessive glabrous	Normal	90	20	82.5	27.5	3	1	4.76

Deviations from expected numbers on the basis of a 3:1 ratio are rather large. It is believed that in crosses 44 and 46 these may be accounted for by difficulties in classification. The recessive glabrous plants are very small and weak and their leaves are dull and drab, appearing to lack the normal amount of chlorophyll. Hence, it was impossible in many cases to determine whether the plants were variegated and this likely accounts for the abnormally low number of variegated plants recorded. In crosses 44 and 46, variegated plants were deficient but in cross 1 they were in excess of expectation. Cross 46 is the only one that showed a significant deviation and this, as stated above, was likely due to unavoidable errors in classification. While the evidence is not conclusive, nevertheless no reason is apparent for believing that any other interpretation would fit the facts better. Hence, variegation (v_1) is considered to be a simple recessive to normal green.

$V_1\,v_1$ appeared to show no linkage with any genes involved in the above crosses. The data indicated independence between $V_1\,v_1$ and

Gg, *Ll*, and the inhibition series of multiple allelomorphs I, i^i, i^k, and i affecting seed color.

POD-BEARING HABIT

As in the common bean, *Phaseolus vulgaris* (Emerson, 1), there are two general growth or pod-bearing habits in the soybean, namely, determinate and indeterminate. These are described by Etheridge, Helm, and King (2) as follows: (a) "a dense array of pods on the central stem, terminating there in a blunt apex, with a thin dispersal on the lateral branches; and (b) a sparse and comparatively even distribution of pods over all branches and stems, a diminishing frequency toward the tip of the central stem being notable." Determinate plants are characterized by stems which are terminated by a raceme bearing several pods. The Peking variety is a good example. In the indeterminate type there is no terminal raceme; the number of pods per node decreases as the tip of the stem is approached and at the tip there is usually only one pod A good example of this type is the Illini variety. Indeterminate stems are usually longer with more nodes than determinate stems.

In inheritance the indeterminate habit is dominant to the determinate. The simple 3:1 ratio obtained indicates that a single gene pair, *Dt dt*, is involved. The following data on a segregating row that traces back to a cross between Manchu and Ebony were recently obtained. Only the main stems were used for comparing the two types of plants.

Type	No. of plants	Ave. length, cm	Ave. No. nodes	Ave. plant yield, grams
Determinate.....	21	94 ± .67	18.6 ± .23	7.4
Indeterminate....	57	131 ± 1.01	26.0 ± .22	10.2

The average internode length is about the same for each type, the difference in height being due to the difference in number of nodes. Thus, the genes *Dt dt* not only differentiate between two modes of bearing pods, but there is an indication that they may also be responsible for a difference in number of nodes.

QUANTITATIVE CHARACTERS

Numerous crosses between soybean varieties have been made at the University of Illinois for the purpose of studying the inheritance of characters having to do with the physiology and performance of the plant. Among these are the following, each of which will be discussed in order: Softness vs. hardness of seed coat, hybrid vigor, and seed yield.

SOFTNESS VS. HARDNESS OF SEED COAT

Hard seeds are common in various legumes, and among soybean types there are some that are slow to take up or imbibe water. Such a type is S. P. I. 65388, a small, brown-seeded sort. The cross between this type and Dunfield, above referred to, furnished evidence on the inheritance of differential rapidity of absorbing water, as Dunfield, like all yellow varieties studied, absorbs water quite readily.

Dunfield has a yellow seed coat with a light brown hilum, while S. P. I. 65388 has a self-brown coat. Seeds produced by the F_1 plants were yellow with black hilum. The genes $R_1 r_1$, $R_2 r_2$, and $i^i i$ were involved in this cross, and consequently three seed-color types were produced in the F_2 in the following ratio:

Coat color	Actual numbers	Expected numbers	Expected ratio
Yellow	208	201	48
Black	34	37	9
Brown	25	29	7
	267	267	64

$\chi^2 = 1.030$, P = 597

F_2 plants were tested for rapidity of water absorption by soaking 10 seeds of each plant in water at a temperature of 80°F. Seeds of the two parents were tested at the same time. Twenty-five seeds of one F_1 plant were tested the year previous in water at room temperature along with seeds of the two parental types. The tests on F_2's were run for 8 days, and records were made of the number of beans swelled after 3 hours, 24 hours, and each 24-hour period thereafter. To express the results numerically, an expression for "average-bean-hours" was calculated for each plant by multiplying the number of beans swelled by the time in hours, adding the products, and dividing by 10. Since the tests were concluded at the end of 8 days, the values for the hardest seed types were not as high as they would be had the experiment been continued longer. By this method of calculation the highest possible value was 192. This was also the value for plants, one or more seeds of which swelled at the end of 8 days but not before. Thus a scale was worked out ranging from 3 to 192, by means of which parents and hybrids were classified, soft seeds being represented by low values and hard seeds by high values. Dunfield fell in the lowest class with a mid-value of 10, and S. P. I. 65388, the other parent, fell in next to the highest class with a mid-value of 170. The F_1 was intermediate, but nearer the Dunfield, falling in the third class with a mid-value of 50. The results for the F_2 plants are given in Table 3 and presented graphically in Fig. 2.

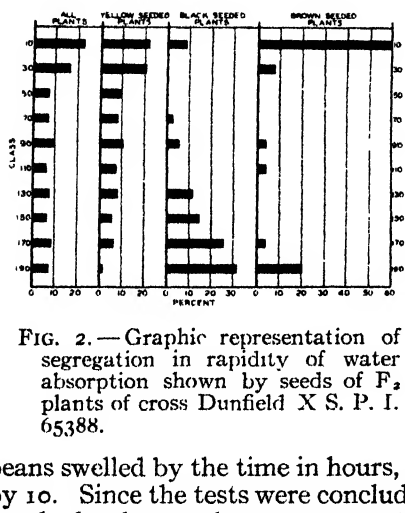

FIG. 2.—Graphic representation of segregation in rapidity of water absorption shown by seeds of F_2 plants of cross Dunfield X S. P. I. 65388.

The distribution for all F_2 plants is not normal. There is a piling up at the "soft" end of the distribution, but after the first two classes the percentages are quite similar. This fact indicates that abil ty to

take up water rapidly is at least partially dominant, and this is also in line with the behavior of the F_1. Trangressive segregation was illustrated in this material. A few F_2 plants were softer than the soft parent and many more were harder than the hard parent. The seeds of several F_2 plants were so hard that no swelling occurred even after remaining in water for 8 days.

TABLE 3.—*Segregation in rapidity of water absorption shown by seeds of F_2 plants of cross Dunfield X S. P. I. 65388.*

Class	Mid-value	All plants		Yellow-seeded plants		Black-seeded plants		Brown-seeded plants	
		No.	%	No.	%	No.	%	No.	%
0-20	10	61	22.6	45	21.7	3	8.6	15	60.0
20-40	30	45	16.7	42	20.3	0	0.0	2	8.0
40-60	50	20	7.4	19	9.2	0	0.0	0	0.0
60-80	70	19	7.0	17	8.2	1	2.9	0	0.0
80-100	90	25	9.3	22	10.6	2	5.7	1	4.0
100-120	110	17	6.3	15	7.3	0	0.0	1	4.0
120-140	130	21	7.8	17	8.2	4	11.4	0	0.0
140-160	150	18	6.7	12	5.8	5	14.3	0	0.0
160-180	170	24	8.9	14	6.8	9	25.7	1	4.0
180-200	190	20	7.4	4	1.9	11	31.4	5	20.0

Furthermore, there appeared to be a relation between the relative rapidity of absorbing water and seed coat color. As previously mentioned, three types of plants were obtained, namely, yellow, black, and brown; and these occurred approximately in the ratio of 48:9:7. When the yellow-seeded F_2 plants were classified separately, they gave a distribution closely approximating that for the whole population (Fig. 2). However, in the case of the black-seeded plants, there was a piling up at the "hard" end of the distribution, though a few were as soft as the soft parent. Just the opposite was true in the case of the brown-seeded plants. More than half, or 60%, of the brown-seeded plants had a mid-value of 10 and 20% had a mid-value of 190, thus giving rise to a U-shaped curve.

The apparent relationship between seed coat color and relative rapidity of absorbing water was believed to be genetic for the reason that "cross-over" types were secured. Thus, nearly all the blacks were hard, having a value considerably above 100, but a few black-seeded plants were obtained about as soft as the soft parent. If the presence of black pigment in the coat or some quality associated with it were sufficient to cause a seed to be hard, then it would be expected that all seeds possessing black pigment would behave similarly. Furthermore, while the hard parent had brown seeds, the F_2 brown-seeded plants were predominantly soft. If brown pigment or some quality associated with it were responsible for the hardness of its seed coat, then all brown-seeded F_2 segregates would be expected to be hard.

Further evidence that this relationship is genetic was furnished by the results of an attempt to determine the particular seed color gene involved. Certain pertinent facts pointed to the R_2T locus. The brown parent (hard seed coat) brought R_2T genes into the cross

and the yellow parent (soft seed coat) brought in r_2t. No black-seeded plants of constitution R_2t were produced in F_2, indicating that no cross-overs between R_2 and T occurred. As was mentioned above, most of the black segregates were hard; in fact, only 6 were below 100, and only 3 were as soft as the soft parent. Of the 25 F_2 brown-

FIG. 3.—Hybrid (B) between Illini (A) and S. P. I. 65388 (C). This cross showed more heterosis than cross (Fig. 4) in which A. K. 114 in place of Illini was used as a parent with S. P. I. 65388.

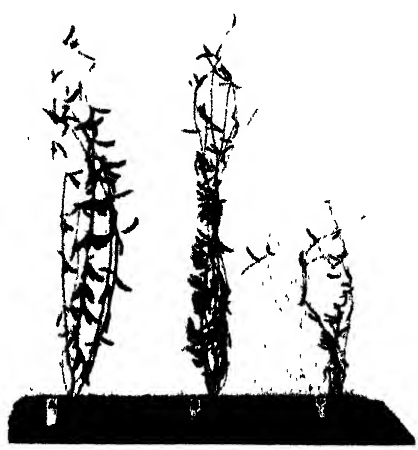

FIG. 4.—Hybrid (B) between A. K. 114 (A) and S. P. I. 65388 (C). This cross showed less heterosis than cross (Fig. 3) in which Illini instead of A. K. 114 was used as a parent with S. P. I. 65388.

seeded plants, 9 were considered to have genes R_2T, and 16 genes r_2t. Only two plants of the R_2T class were below 100; five were above 175; and the average was 141.9. In contrast, only one plant of the r_2t type was classed as hard with a value of 192.0, the rest ranging from 3.0 to 21.9; the average being 18.6. It was found difficult and unsatisfactory to make a similar analysis of the yellow-seeded F_2 segregates, though it is worthy of mention that those with tawny pubescence had a higher average than those with gray pubescence. In general, then, the facts substantiate the idea that hardness of seed coat in S. P. I. 65388 may be due mainly to a gene which occurs in the same linkage group with R_2T and is so located as to permit only a small amount of crossing-over to take place.

HYBRID VIGOR

Considerable evidence on the occurrence of hybrid vigor in soybeans has been furnished by Wentz and Stewart (8) and by Veatch (7). Many varieties when crossed show heterosis in many characters having to do with the performance and production of the plant.

In two crosses recently made at the Illinois Station, one variety was a parent in both. These crosses were (133) Illini X S. P. I.

65388, and (135) A. K. 114 X S. P. I. 65388. Much more hybrid vigor was evident in cross (133) than in cross (135). (See Figs. 3 and 4.) The data are given in Table 4. This difference is difficult to account for. A. K. 114 and S. P. I. 65388 differ in many quantitative characters; so also do Illini and S. P. I. 65388, but in addition Illini differs from S. P. I. 65388 in two characters—pubescence color and flower color. It does not seem reasonable, however, that the difference in these qualitative characters can account for the excess in hybrid vigor shown by cross (133) over cross (135).

A third cross was made between A. K. 114 and a fasciated type obtained from Japan. Not only was normal pod-bearing habit dominant in this cross, but considerable hybrid vigor was shown. These data are given in Table 4, also.

A problem of major interest for plant breeding is the utilization of hybrid vigor for increased production in the soybean. It cannot be utilized in the same way as in corn because of the difficulty in making crosses. If in the F_2 generation, plants could be found that are homozygous for all the genes for which the F_1 is heterozygous, they should breed true for the increased vigor. Veatch (7) secured considerable data on F_2's of four crosses. He found considerable variation in vigor and production, and a few extremely productive plants. However, when these were tested in F_3, they failed to produce high yielding progeny.

SEED YIELD

Seed yield is an extremely complex character which is the end result of numerous growth activities of the plant. On account of this extreme complexity it has seemed best to attempt to resolve the character into simpler components and to study each separately. With this in mind many soybean varieties representing different habits of growth have been compared on a plant basis for the following components: Number of nodes, number pods per node, number seeds per pod, percentage abortive seed, and size of seed. The results are set forth in Table 5.

The attempt was made to grow these varieties in such a way that the results for each variety would be comparable with those of any other. To this end, 10 replications of 10 plants each were used for each variety, and these replications were scattered systematically about the plat so that each variety may be said to have been subjected to much the same growth conditions. To avoid end-to-end varietal competition, 12 plants were grown in each replication and the plant on each end discarded. Perfect stands were obtained by planting two seeds in a hill and thinning to one plant. The seeds were spaced 2 inches apart in the row, the rows being 2 feet, 6 inches apart.

A study of Table 5 reveals many interesting facts. Varieties differed greatly and significantly in all yield components studied. No one variety was superior and no one variety inferior to all the others in all components. Some were high in certain components and low in others. For example, certain varieties bore pods that were predominantly three-seeded, while others were predominantly two-seeded. This comparison is brought out much better in Fig. 5. Some varieties showed much less seed abortion than others. There was also a great difference in average weight of seed or seed size.

TABLE 4.—*Data on parents and hybrids showing various degrees of hybrid vigor.*

Type	No. of plants	Ave. No. branches	Ave. No. nodes per plant	Ave. length main stem, cm	Ave. length branches, cm	Ave. No. pods	Average percentage 2-seeded pods	Average percentage 3-seeded pods	Abortive seed, %	Ave. weight seed per plant, grams	Ave. weight 100 seeds, grams
Illini	2	4.0	47.5	104	201	81.0	29.4	67.5	24.7	23.0	12.6
S. P. I. 65388	3	3.7	43.0	70	140	39	18.8	76.9	28.9	3.9	5.1
Hybrid (X 133)	3	6 3	116.3	142	720	190	18.0	79.5	32.1	36.0	8.3
% increase over parental average		62.3	157.0	63.0	322.3	216.7				166.7	— 3.4
% increase over higher parent		57.5	145.0	36.5	258.2	134.6				56.5	—33.1
A.K 114	3	3.7	49.3	79	182	89	34.2	63.9	15.8	25.2	12.8
S. P. I. 65388	2	5.0	55.5	61	185	39	29.5	60.3	47.3	2.5	4.4
Hybrid (X 135)	2	6.0	84.5	98	470	132	18.6	76.9	28.3	19.1	7.3
% increase over parental average		38.0	61.4	40	156	106.3				37.9	—15.1
% increase over higher parent		20.0	52.3	24	154	48 3				—24.2	—43.0
A. K. 114	3	3.7	49.3	79	182	89	34.2	63.9	15.8	25.2	12.8
Fasciated	1	—	——	80	——		89.4	2.3	16.3	43.8	12.4
Hybrid (X 144)	3	5.0	78.3	109.7	308.7	179	76.7	17.9	6.5	60.9	15.7
% increase over parental average				38.0						76.5	24.6
% increase over higher parent										60.3	22.7

TABLE 5.—*Average values of yield components for 26 soybean varieties, 1930 data.*

Variety name or No.	Ave. number nodes per plant	Ave. number pods per node	Ave. number seeds per pod	Abortive seed, %	Ave. weight 100 seeds, grams	Average yield per plant, grams
Mandarin	22.33±.344	1.12±.018	2.12±.015	31.60±.128	14.01±.138	4.84±.140
Brown Type 30	21.95±.368	1.24±.015	2.46±.016	30.39±.054	12.23±.104	5.77±.151
A. K. 114	19.67±.283	1.19±.018	2.50±.011	17.33±.507	16.11±.103	8.22±.204
Ito San	27.62±.636	1.13±.014	2.11±.013	17.35±.442	15.23±.107	8.30±.219
Illini	21.09±.393	1.33±.024	2.73±.008	16.96±.523	14.88±.096	9.82±.144
Manchu	23.31±.487	0.84±.021	2.52±.015	17.56±.604	18.04±.093	7.04±.223
Wea	22.37±.494	1.25±.023	2.42±.015	24.25±.652	14.82±.015	7.46±.224
Black Eyebrow	24.67±.513	0.97±.016	2.13±.016	21.36±.081	18.21±.177	7.79±.249
Mansoy	23.54±.340	0.99±.024	2.19±.011	18.42±.573	17.54±.100	7.72±.267
Harbinsoy	26.31±.458	1.04±.026	2.08±.013	14.94±.465	14.56±.098	7.55±.250
Ebony	36.69±.407	0.93±.026	2.07±.024	26.09±.662	10.84±.122	6.48±.248
S. P. I. 65394	19.43±.345	1.27±.018	2.65±.009	18.61±.501	13.35±.085	7.72±.210
Ohio 13-177	29.22±.612	1.08±.022	2.37±.012	25.07±.094	15.37±.131	8.91±.270
West Virginia 8	33.93±.645	1.17±.025	2.13±.015	25.24±.659	11.47±.094	7.48±.237
Peking	42.47±.349	1.50±.034	2.22±.009	24.31±.535	7.64±.074	8.29±.256
Virginia	25.53±.594	1.25±.032	2.00±.018	21.54±.627	11.84±.075	5.71±.210
Ilsoy	28.90±.506	1.27±.018	2.19±.011	22.09±.557	12.18±.100	8.09±.210
S. P. I. 04002-B	25.38±.578	0.99±.022	2.68±.009	18.16±.538	15.54±.126	8.91±.243
S. P. I. 54610-3	24.97±.418	1.04±.020	2.71±.009	20.69±.482	13.23±.111	7.80±.235
S. P. I. 65388	30.14±.018	1.04±.020	2.77±.008	23.90±.590	4.94±.049	3.30±.103
S. P. I. 54592	36.22±.376	0.86±.019	2.70±.013	20.56±.477	14.75±.100	10.22±.375
Aksarben	23.31±.500	1.14±.025	2.36±.014	18.56±.013	15.87±.148	8.49±.277
Morse	34.07±.248	0.74±.013	2.14±.024	19.62±.619	16.59±.146	7.62±.290
S. P. I. 65345	21.42±.426	1.32±.020	2.07±.007	16.94±.466	14.91±.115	7.22±.229
Dunfield	22.94±.641	0.88±.022	2.35±.016	18.84±.660	16.95±.146	7.02±.250
Wilson 5	44.83±.274	1.02±.018	2.16±.011	26.49±.525	7.91±.073	5.98±.163

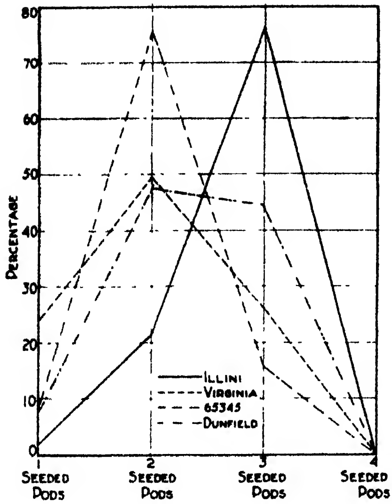

Fig. 5.—Varieties of soybeans differ greatly in proportion of two- and three-seeded pods. Some are predominantly two-seeded, while others are predominantly three-seeded. Illini is a three-seeded type, while the others represented in the diagram are two-seeded, though Dunfield has nearly as many three's as two's.

Yield curves were constructed for each variety by expressing each of the yield components as a percentage of the maximum. By means of such yield curves, varieties were readily compared with one another. Thus, in two instances, two varieties gave the same yield per plant, but that particular yield was arrived at in different ways. (See Fig. 6.) One variety exceeded the other in certain components, and *vice versa*. The yield curves for the highest and lowest yielding varieties in the experiment were similar except for size of seed (Fig. 7). As a result of these studies, we regard a variety as a biotype, each with its own particular complex of characters and its own particular yield performance which may be the same as that of another variety but arrived at in a different way, or which may be higher or lower due to a difference in one or more yield components.

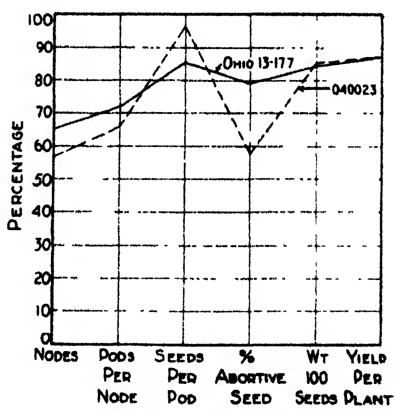

Fig. 6.—Varieties Ohio 13–177 and S. P. I. 040023 gave the same yield per plant. By expressing each yield component as a percentage of the maximum, yield curves were constructed showing, in this instance, that the same plant yield was arrived at in different ways. One variety exceeded the other in certain components, and *vice versa*.

GENETIC CORRELATIONS

In a former paper, the author (9) has discussed the problem of determining the genetic correlation between yield components and yield and between the components themselves. Two ways of doing this were described. In the first, Pearson's correlation coefficient (r) could be calculated using the means of the several varieties for the several characters as separate items. Pearson's r was calculated for the data obtained in 1930 on 26 varieties of soybeans, and the results are given in Table 6.

The yield components studied do not show close relationships to yield. Other results might have been secured if a larger number of

varieties or if different varieties had been used. Coefficients (r) obtained for percentage of abortive seed and yield and average weight of 100 seeds and yield are significant in relation to their probable errors, and also from the standpoint of Fisher's criterion (3) even when the level of significance, P = .01, is applied. The other components show little or no relation to yield. The explanation for this appears to be that the effect of a component from the yield standpoint may be entirely nullified by the effect of another or of other components. Varieties, however, with high percentage of abortive seed and small seeds tend to be low yielders and varieties with low percentage of abortive seed and large seed tend to be high yielders.

Similarly, the yield components do not seem to show close relationship with one another. Coefficients (r) for number of nodes and average weight of 100 seeds and for percentage of abortive seed and average weight of 100 seeds are high enough to be significant by Fisher's criterion; all others are too low. Thus, from these data it may be concluded that the larger seeded varieties tend to have a high number of nodes and a low percentage of abortive seed; but that,

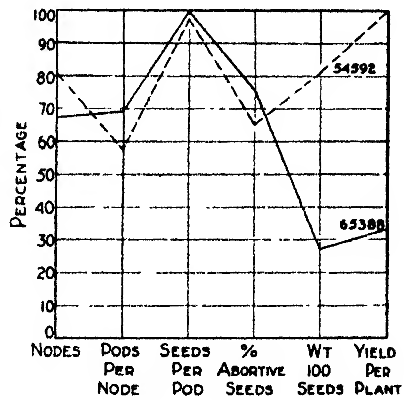

FIG. 7.—Variety S. P. I. 54592 gave the highest plant yield and variety S. P. I. 65388 the lowest plant yield in the test. However, these varieties were fairly similar in all components except size of seed.

TABLE 6.—*Correlation coefficients between yield components and yield and between the components themselves* *

Characters correlated	Pearson (r)
Number nodes and plant yield	+.019±.132
Number pods a node and plant yield	+.191±.127
Number seeds a pod and plant yield	+.200±.127
% abortive seed and plant yield	−.521±.096
Average wt. 100 seeds and plant yield	+.519±.096
Number nodes and number pods a node	−.184±.128
Number nodes and number seeds a pod	−.193±.127
Number nodes and % abortive seed	+.347±.116
Number nodes and average wt. 100 seeds	−.592±.086
Number pods a node and number seeds a pod	−.101±.131
Number pods a node and % abortive seed	+.159±.128
Number pods a node and average wt. 100 seeds	−.382±.112
Number seeds a pod and % abortive seed	−.238±.125
Number seeds a pod and average wt. 100 seeds	−.047±.103
% abortive seed and average wt. 100 seeds	−.520±.096

*Data on 26 soybean varieties, 1930.

in the main, the yield components are independent of one another in inheritance.

The second method (Woodworth, 9) of determining genetic relationships involves crossing varieties having particular combinations of the component characters, and comparing the proportions of new combinations obtained in F_2 with those expected on the basis of independence. This method has not been used, but material is on hand at present which may indicate to what extent the method is feasible. Yield components are quantitative in nature, and hence are greatly influenced by environmental conditions. For these reasons the problem is complicated, but it is considered not to be altogether impossible of solution.

SUMMARY

1. A list of genes and a chromosome map are given to show the progress made to date in a genetic analysis of the soybean.

2. The mode of inheritance of three characters is described. Bloom on the seed coat is considered to be due to three complementary genes B_1, B_2, and B_3, all three of which must be present to produce the character. Variegated leaf (v_1) is a simple recessive to normal (V_1), and determinate pod-bearing habit (*dt*) is a simple recessive to indeterminate habit, (*Dt*).

3. Data on the inheritance of hardness vs. softness of seed coat are presented. Ability to imbibe water readily appears to be partially dominant in the F_1, and in F_2 there is wide variation, a few segregates even transcending the limits of the parents, thus illustrating transgressive segregation. A relation to seed color was indicated, and the color genes involved in this relationship were thought to be R_2T.

4. Hybrid vigor was illustrated in three crosses, in two of which one variety was a common parent. In one of these two crosses much more heterosis was evident than in the other.

5. An attempt was made to resolve seed yield into simpler components, to study each separately, and to compare varieties with respect to each. As a result of these studies a variety was thought of as a biotype, having its own complex of characters each expressed to a certain degree, the end result of which may be the same as for another variety, but attained in a different way.

6. Genetic correlations were calculated between the yield components and yield and between the components themselves. Little relationship was indicated between these and yield, though it appeared that varieties with high percentage of abortive seed and small seeds tend to be low yielders and varieties with low percentage of abortive seed and large seed tend to be high yielders. In general, the yield components showed no significant correlations with one another. However, it may be concluded that large-seeded varieties tend to have a high number of nodes and a low percentage of abortive seed.

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A REVIEW OF RESEARCHES ON NITROGEN FERTILIZATION IN RELATION TO ECONOMIC CROP PRODUCTION WITH SPECIAL REFERENCE TO FUTURE INVESTIGATIONS[1]

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During recent years the practical importance of nitrogen fertilization has attracted increasing attention. Special emphasis has been placed on the research phases of the subject. In Europe a large part of the attention of investigators has been given to the more practical aspects of the problem. In each of several countries large numbers of plat experiments have been made on individual farms. In America the researches have been conducted along both scientific and practical lines, but with less emphasis on field experiments.

It is well known that nitrogen is subject to important losses from soils by leaching and volatilization, perhaps more so than any other element. The aggregate amount of nitrogen that is removed from the soil in the harvested crops is considerable Where no special precautions are taken, the yields of crops frequently decline after a few years of intensive cropping, owing in part at least to the inadequacy of the nitrogen supply. In harmony with these facts practical experience has shown that the application of nitrogen fertilizers often markedly stimulates the growth of crops.

EFFECT OF NITROGEN ON CROP YIELDS

In addition to the long-established plat experiments at the Rothamsted and Woburn Stations in England and at certain American

[1]Paper No. 270, University of California Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, Calif.

The study upon which this report is based was sponsored by the American Society of Agronomy because of its relation to the prize which was formerly awarded annually by the Society for the best researches on nitrogen in relation to economic crop production. Also, it was believed that a survey of this subject would be useful to the research workers in this field. The University of California authorized the investigation because of the importance of nitrogen fertilization to California agriculture. The writer wishes to acknowledge the aid of many colleagues and friends in different countries, and the cooperation and assistance of the Chilean Nitrate of Soda Educational Bureau of New York, the founder of the Nitrogen Research Award of the American Society of Agronomy. Received for publication May 2, 1932.

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experiment stations, many experiments are being made annually on the farms of certain European countries and to a lesser degree in the United States. Results of great practical value are thus being obtained.

For many years the Farmers' Unions of Denmark (17)[3] have annually conducted large numbers of plat experiments on the members' farms. The primary object having been to determine the effect of nitrogen, every plat has been treated with liberal applications of superphosphate and sulfate of potash in order to insure adequate supplies of phosphoric acid and potash; every treatment that was applied in a given experiment was replicated four or five times on each farm; and the experiments have been repeated on a considerable number of farms in various parts of Denmark each year for three successive years. The results that were obtained in 1928, 1929, and 1930 are summarized in Tables 1 and 2.

TABLE 1.—*Comparative effect of Chilean nitrate and ammonium sulfate compiled from reports of Danish experiments for 1928-30.**

Crop	No. of experiments	Yield in pounds per acre				
		Without nitrogen	With Chilean nitrate	With ammonium sulfate	Increases*	
					Chilean nitrate	Ammonium sulfate
Wheat	16	2,815	3,511	3,373	696	558
Barley	24	2,716	3,271	3,204	555	488
Oats	13	2,503	3,011	3,053	508	550
Rye	17	1,657	2,403	2,330	746	673
Sugar beets	23	25,149	29,534	27,923	4,385	2,774
Mangolds	32	51,910	65,335	59,607	13,425	7,697
Turnips	28	55,937	66,945	66,856	11,008	10,919
Potatoes	11	17,363	20,853	21,480	3,490	4,117

*27 pounds per acre of actual nitrogen were applied to wheat, barley, oats, and rye; 54 pounds to sugar beets, mangolds, turnips, and potatoes. All plats were treated uniformly with superphosphate and sulfate of potash.

TABLE 2.—*Comparative effect of Chilean nitrate and calcium nitrate compiled from reports of Danish experiments for 1928-30.**

Crop	No. of experiments	Yield in pounds per acre				
		Without nitrogen	With Chilean nitrate	With calcium nitrate	Increases*	
					Chilean nitrate	Calcium nitrate
Wheat	10	2,443	2,904	2,928	461	485
Barley	9	2,172	2,667	2,648	495	476
Rye	9	1,326	1,949	1,973	623	647
Sugar beets	34	27,476	31,951	30,787	4,475	3,311
Mangolds	26	51,820	64,529	59,517	12,709	7,697

*27 pounds per acre of actual nitrogen were applied to wheat, barley, and rye; 54 pounds to sugar beets and mangolds. All plats were treated uniformly with superphosphate and sulfate of potash.

[3]Reference by number is to "Literature Cited," p. 63.

By reference to the tables it will be seen that the application of nitrogen fertilizer produced substantial increases in the yield of various crops. Although an average of more than 40 bushels (2,443 to 2,815 pounds) of wheat per acre (approximately three times the average American yield of wheat) was obtained without the application of nitrogen fertilizer, substantial increases were obtained by applying nitrogen. Similar results have been obtained with other crops. The high yields obtained in these experiments are probably due in part to the excellence of the Danish system of farming, which always embraces systematic crop rotation with grass and clover grown in each rotation, and the utilization of relatively large amounts of animal manures.

The extensive system of practical experimentation which has been developed in Germany during the past 10 years under the auspices of the various *Versuchsringen* (experimental unions) has also included many experiments with nitrogen fertilizers. In a number of localities the results have been very similar to those reported from Denmark. These tests have shown that it is profitable to apply nitrogen fertilizers to the various crops and soils in Germany As in Denmark, the German farmers have long practiced a system of crop rotation which regularly included legumes, and the art of manure conservation is highly developed and intensively practiced Nevertheless it has been found that nitrogen fertilization is distinctly profitable.

Tests made in various parts of the United States have also shown that under the systems of farming as practiced in many localities nitrogen fertilizers produce marked effects. This is true as regards both the staple crops and special types of crops such as fruit trees and truck crops. For example, recent experiments have shown that various crops in the state of Washington may be marked y stimulated by the application of nitrogen fertilizers. It is well known that the yield of cotton in the southern states is often notably increased by nitrogen fertilizers. The citrus orchards of California and Florida actually require nitrogen fertilization for profitable fruit production. Anthony (2) and others have shown that nitrogen is an important element in the fertilization of the apple trees of Pennsylvania and other eastern states.

During recent years the value of nitrogen fertilizer as a top dressing for pasture lands has also been demonstrated in several localities in America and England.

The foregoing discussion refers to only a few of the many plat experiments that have been made with nitrogen fertilizers. The total number of such experiments now regularly conducted in various parts of the world is very large. There is a growing recognition of the importance of this type of research. The results have shown that the application of nitrogen fertilizer may effectively increase the yield of various kinds of crops. This applies to soils of widely different type and previous condition of cropping and treatment. The stimulating effect thus produced is not necessarily limited to soils of low productive power, nor to systems of crop rotation which do not include legumes.

Although the above-named facts are well established, the view is held in various parts of America that, if the farmer employs a good system of crop rotation in which legumes are regularly grown and especially if crop residues and farm manures are properly conserved and utilized, it will not be profitable to apply nitrogen fertilizers. In harmony with this idea White and Holben (22) recently pointed out that the application of nitrogen fertilizers in the rotation experiments of the Pennsylvania Experiment Station has not been profitable, although considerable increases in yield have been produced by the applications.

A satisfactory explanation of the conflict of evidence on this point can not now be given. It is possible that variations in the tillage and the general preparation of the soil may modify the effects of nitrogen fertilizers to an important extent and it is certain that climatic conditions profoundly modify the action of fertilizers. It should be emphasized that with certain crops the economic value of soluble nitrogen fertilizer is dependent in considerable measure on the time and mode of application. Not infrequently the best results are obtained by applying part of the nitrogen some weeks after the crop has germinated. To obtain maximum yields of winter cereals it may be necessary to apply some soluble nitrogen fertilizer as a top dressing in the spring.

As is well known, the factors that influence the action of fertilizers in general, including nitrogen, vary from place to place to an important degree; consequently the results obtained in one locality, or with one crop, can not be accepted as a safe guide for another locality or for a different crop. Local field experiments are therefore especially valuable as a means of ascertaining the nitrogen requirements of a given soil and crop.

EFFECT OF NITROGEN ON THE QUALITY OF THE CROP

During recent years experiments in various parts of England and America have demonstrated the practical value of applying soluble nitrogen as a top dressing to pasture lands. Evidence has been obtained in certain places which indicates that the application of different nitrogen fertilizers may affect the palatability of the pasture herbage unequally, but definite knowledge on this point is lacking. In most of the experimental work on pasture fertilization attention has been focused primarily on the yield as affected by the time and rate of application of the fertilizer materials. Recently, Gardner, *et al.* (8), have studied the nutritive value of a pasture as affected by ammonium sulfate. In this investigation the total yields and the protein content of each of the important species of plants in the pasture were determined and a part of each plat was pastured off by cattle, the gains in the weights of the animals being recorded. Still more completely controlled investigations of a similar nature are being conducted by the research staff of the Imperial Chemical Industries Limited of England (21). There is need for much additional research on pasture fertilization.

The results obtained by several investigators have indicated that the baking quality of wheat flour is related to the protein content

of the grain and that the protein content of the grain may be influenced to an important degree by nitrogen fertilization. It has been found possible to convert certain types of soft wheat into hard wheat by proper control of the available nitrogen supply. On the other hand, recent investigations in England (7) have indicated that the nitrogen content of the grain is not necessarily directly related to the baking quality of its flour. In view of the fact that high protein wheats command a higher price than soft wheats it is important that the various factors which influence the properties of the grain be thoroughly studied. There is need for research on all phases of this question.

As already suggested, numerous experiments have shown that in many localities nitrogen fertilizer produces more marked effect on fruit trees than other fertilizer elements both as regards the yield of fruit and the thrift of the tree. It has long been believed that the relationship between carbohydrates and nitrogen within the tissues of the tree has much to do with fruit bud formation and fruit setting, but the essential factors that are concerned with the nutritional processes of fruit trees have not been adequately investigated.

Several investigators have been engaged with this problem. Wallace (20) and his associates in England have made especially important contributions to our knowledge of the nutrition of deciduous fruit trees. The essential features of the method that they have successfully employed will undoubtedly prove useful elsewhere. Briefly, it consists in controlling the nutrition of the tree through control of the nutrient medium available to its roots and then studying the resulting properties of the tissues and the fruit. Results of great importance to the fruit growers of England have already been secured by these investigators. Certain difficulties which previously baffled the practical fruit grower have been elucidated by these investigations and practical remedies have been developed.

The composition, color, and keeping quality of different fruits and their susceptibility to attack by fungi are important aspects of fruit production. Wallace has found that the nutrient conditions of the apple tree markedly influence the keeping quality of the fruit and the flavor of cider made from the same. It is important that we have a careful investigation of the nitrogen fertilization of various kinds of fruit trees in relation to these and similar questions.

That nitrogen fertilization may play an important part in the success of sugar cane culture is well established Intensive investigation on certain of the sugar plantations in Hawaii have shown that the yield and the profit of sugar may be augmented by the application of nitrogen fertilizers at the proper stage in the growth of the cane. It has been found that both the time of application and the form of nitrogen not only influence the yield of sugar cane but also markedly affect the milling quality of the extracted juices, and that different portions of a given plantation may respond differently to nitrogen fertilizer. The practical importance of this work is shown by the fact that by applying the results of these investigations the yields and profits have been substantially increased on these plantations.

THE RELATION OF NITROGEN TO OTHER ELEMENTS

As is well known, it has long been claimed that the chief function of potassium in plant growth is in connection with carbohydrate synthesis and translocation, but this view has never been adequately established experimentally. Unpublished experiments by Hoagland and Davis[4] with barley suggest that potassium is involved in an important way in protein synthesis. The work of Wallace (19) and Gildehaus (9) suggests the possibility of a similar relationship between nitrogen and potassium in the growth and development of the apple tree.

This point is mentioned here because of the possibility that the investigation of nitrogen fertilization and nitrogen nutrition of plants may necessitate the giving of detailed consideration to the relation of nitrogen to the other nutrient elements. Since the results of research in this field must ultimately be considered in relation to the general physiological processes of the plant as a whole, the investigator should strive to avoid overspecialization with its tendency to narrowness of view. The relation which nitrogen bears to other elements in the nutritional process is probably so interrelated that an understanding of the one is dependent upon knowledge of the other. In any type of experimental work with nitrogen fertilizers it is very important to provide adequate supplies of available phosphate and potash. If the soil should be deficient in these or other nutrients or if the pH of the soil be unfavorable, nitrogen fertilizers may not produce their best effects.

EFFECT OF DIFFERENT NITROGEN FERTILIZERS

It is well established that crops are not always affected to the same degree by a given amount of nitrogen when applied in different forms. Several investigations have shown, for example, that ammonium sulfate may produce much better effects with rice than nitrates. On the other hand, nitrates may be more effective than ammonium sulfate with certain other crops and in certain soils the different nitrate materials seem to produce significantly different effects.

Referring again to Tables 1 and 2 it will be noted that in the Danish experiments, Chilean nitrate produced significantly greater yields of sugar beets and mangolds than ammonium sulfate or calcium nitrate. On the other hand, ammonium sulfate was the more effective with potatoes. Similar results have been reported from other localities. In the experiments with cereals and turnips the effects of nitrate and ammonium forms of nitrogen, although more nearly the same, were still somewhat different. Since these experiments were repeated on various farms in Denmark for three successive years with remarkably consistent results, it is possible that relatively small differences in the yields are significant. It will be noted that as an average of 16 experiments the application of 27 pounds of nitrogen per acre in the form of Chilean nitrate produced 138 pounds per acre more wheat than was obtained by the same amount of nitrogen as ammonium sulfate. With oats, on the other hand, ammonium sulfate gave slightly greater yields than Chilean nitrate.

[4]Personal communication.

From a scientific standpoint the question may be asked, why does Chilean nitrate produce greater yields of sugar beets and mangolds than ammonium sulfate or calcium nitrate, whereas ammonium sulfate is more effective with potatoes than Chilean nitrate? It has been suggested that the sodium of Chilean nitrate may exert a favorable effect on the root crops, while the potato plant prefers ammonium forms of nitrogen. It is also possible that in certain soils ammonium sulfate produces a condition of acidity more favorable for potatoes than Chilean nitrate, since it is known that an increase in the acidity of the soil tends to reduce the severity of the potato scab disease. However, the fact that the relative effect of Chilean nitrate and calcium nitrate on the root crops of Denmark was approximately the same as that of Chilean nitrate and ammonium sulfate indicates that pH was not the controlling factor in these cases.

Experiments at the Mississippi Delta Station have indicated differences in the value of different nitrogenous materials as fertilizers for cotton somewhat like those referred to above from Denmark. As an average of 5 years' tests, it was found, for example, that 30 pounds per acre of actual nitrogen gave increases in the yield of cotton as follows: Sodium nitrate, 457 pounds; ammonium sulfate, 376 pounds; leunasalpeter, 326 pounds; calcium nitrate, 285 pounds; and urea, 340 pounds In Alabama and other states it has been shown that a side dressing of nitrate of soda applied to cotton at the proper stage of growth may be considerably more profitable than a corresponding application of ammonium sulfate. In harmony with the results of these tests many farmers have shown a preference for Chilean nitrate, especially in the southeastern states where considerable amounts of soluble nitrogen are used as side dressings for cotton and corn.[5]

A series of tank experiments that has been conducted at the New Jersey Experiment Station since 1898 (11) has yielded important data on the nutritional efficiency of nitrate of soda, ammonium sulfate, and dried blood. In these experiments nitrate of soda has given somewhat better results, both as regards yields and nitrogen absorption by the crops, than ammonium sulfate or dried blood. It is probable that by the expansion of this type of experiments, which should be conducted through a series of years under controlled conditions with different soils and crops, important information might be obtained concerning the action and value of different nitrogen fertilizers.

The fact that Chilean nitrate produces better effects in certain localities than other nitrogen fertilizers can not now be satisfactorily explained. It is possible that some one or more of the various substances which Chilean nitrate contains as impurities may be involved, since researches during recent years have definitely shown that the addition of small amounts of several different elements may produce marked stimulation in the growth and development of many kinds of plants.

Brenchley (4) has pointed out that the annual application of am-

[5]Fertilizer Review, 7:7–8. 1932.

monium sulfate to the permanent grass plats at Rothamsted has brought about almost complete elimination of leguminous species, while nitrate of soda has produced a less striking effect on the legume population. These differences can not be explained satisfactorily on the basis of soil reaction alone, for divergent effects have resulted from these nitrogen fertilizers when applied in conjunction with complete minerals and lime. The contrast between the effects of ammonium sulfate and sodium nitrate becomes especially noticeable when we consider the total yields of hay that have been produced in consequence of liming the nitrogen-treated plats. When applied in conjunction with ammonium sulfate, lime has markedly increased the yield, whereas only slight effects have resulted from liming the nitrate of soda plat. In fact the annual application of sodium nitrate, without the addition of lime, has maintained a rather high yield throughout the entire history of this experiment (since 1856).

Conflict has often characterized the reports on calcium cyanamid. In a number of the Danish experiments calcium cyanamid was compared with ammonium sulfate. On the basis of results obtained on each of 10 or more different farms, Rasmussen (17) reported that "One kilogram of nitrogen in the form of ammonium sulfate produced the same yields of oats, potatoes, and turnips as 1.67, 1.32, and 1.35 kilograms, respectively, of nitrogen in the form of calcium cyanamid." On the other hand, calcium cyanamid has given as good results as the nitrate or ammonium salts in many of the German experiments. Moyer and Blair (12) recently reported good results from the use of calcium cyanamid in New Jersey.

In certain cases calcium cyanamid has produced more or less injury to crops. In order to guard against the possibility of injury to the germination and seedling stages of the crop, it is often recommended that the application of cyanamid be made some weeks in advance of seeding. However, injury to crops is not always produced by calcium cyanamid. Considerable study has already been devoted to the chemical changes which cyanamid undergoes in the soil, but the exact nature of the toxic effect is not sufficiently understood. There is need for a thorough study of the conditions and factors which influence the action of this material.

EFFECT OF NITROGEN ON LEGUMES

It is commonly believed that under favorable soil consitions the nitrogen-fixing power of legumes enables these plants, if properly inoculated, to satisfy their nitrogen requirement from atmospheric sources; consequently, it is commonly thought to be unnecessary to apply nitrogen fertilizers to leguminous crops. However, evidence has developed here and there which indicates, at least under certain practical farm conditions, that the application of nitrogen fertilizers may markedly stimulate the growth of legumes particularly during the seedling stages. Our knowledge concerning nitrogen fixation, both symbiotic and nonsymbiotic, is inadequate and especially is this true as regards the actual amount of nitrogen that is fixed under practical farm conditions. The prevailing views on this subject are largely based on inference.

CHEMICAL AND PHYSICAL EFFECTS OF NITROGEN FERTILIZERS

It is well known that unless the soil contains calcium carbonate the application of ammonium sulfate will promote the development of an acid condition of the soil (13). The experiments at the Rothamsted, Pennsylvania, and Rhode Island stations have shown that the continued application of ammonium sulfate may lead to excessive acidity. Other ammonium compounds, such as the phosphate, chloride, and nitrate, will probably produce similar effects (1, 15). This acidifying effect of ammonium forms of nitrogen is produced through the agency of nitrification in which the ammonia is converted into nitrate. In this process the acids that are formed combine with the available soil bases, chiefly calcium. It follows then that the continued use of ammonium forms of nitrogen will hasten the exhaustion of the calcium supply of the soil. Although this effect can be counteracted by liming, the acidifying action is nevertheless a positive disadvantage of ammonium forms of nitrogen. Nitrates, on the other hand, tend to conserve the calcium supply (13) and to delay the development of injurious acidity.

In general it may be said that the economic value of nitrogen fertilization is intimately related to the reaction of the soil, and that the efficiency of the different nitrogenous materials is affected by soil acidity and liming to very different degrees. Ammonium salts and organic forms usually produce their best effects in approximately neutral or slightly alkaline soil. On the other hand, the nitrates usually produce good results over a much wider pH range. In making comparative tests of different nitrogen fertilizers it is important to note the pH of the soil and to vary the same by liming.

As was pointed out recently by Pierre (14, 15, 16) and Allison (1), the most important chemical effects that are produced on the soil by nitrogen fertilizers are those which result in the decomposition of calcium carbonate and the replacement by H ions of calcium from the base-exchange material of the soil. Both of these processes lower the buffer property of the soil towards acids and tend towards the development of soil acidity. As was suggested already the different nitrogen fertilizers react with these materials differently. There is need for extended research on the relationships of the several forms of nitrogen to soil reaction and to the lime requirement of the soil.

It has often been noted that the application of sodium nitrate to heavy types of soil may lead to the development of a baked or encrusted condition in the surface soil. In 1904 Hall (10) called attention to certain peculiar effects that had been produced by nitrate of soda at Rothamsted. More recently the writer and others have noticed similar effects in a citrus orchard experiment at Riverside, California. In both cases the soil became more or less deflocculated following the annual application of nitrate of soda for a period of years. There are certain interesting peculiarities in this deflocculating effect which remain to be explained. For instance it seems to become most apparent when the land is cultivated for a considerable part of each year, and even then it may be somewhat transitory.

During recent years the evidence of deflocculation in the Rothamsted soil has diminished rather than increased, and in the California experiment practically all indications of deflocculation have disappeared since leguminous cover cropping was introduced into the experiment.

It has been claimed that the application of sodium nitrate leads to the formation of sodium carbonate in the soil, owing to the greater absorption by crops of NO_3 than of Na, and that the consequent formation of sodium carbonate brings about deflocculation of the soil. However, the presence of sodium carbonate in the soils that have been treated with ordinary applications of sodium nitrate has not been satisfactorily established experimentally. It is more probable that base exchange is primarily responsible for the deflocculation. The sodium clay, formed as a result of base exchange, is more highly dispersed than ordinary clay. However, the evidence is that only very limited amounts of sodium clay are actually formed as a result of practical applications of sodium nitrate. Moreover, the base exchange which is produced under certain conditions by salts of mono-valent bases is effectively prevented by the presence of soluble calcium salts, such as superphosphate, or by the decay of green manures. When used in conjunction with farm manures, green manures, or crop rotation, none of the nitrogen fertilizers seems to produce any important deflocculation of the soil. On the other hand, the use of any calcium salt, such as calcium nitrate, calurea, calcium cyanamid, etc., will undoubtedly tend to maintain the calcium supply of the soil. Theoretically these materials would be expected to produce favorable physical effects through their power of flocculation. None of them produces an increase in soil acidity.

It follows from the foregoing that to understand the effects of a given fertilizer, whether it be nitrogenous or non-nitrogenous, it is necessary to give due consideration to the various constituents which that material contains and to the effects which it produces both on the crop and on the soil. These effects may be chemical, physical, and biological. The investigator in this field must deal with a complex system involving intricate interrelations. The effect of a fertilizer material on the yield of crops may be either a direct consequence of its application or an indirect action brought about through transformations that are produced on the soil. The writer is convinced that a frank recognition of these facts by the research worker will lead to a better understanding of the principles which govern the action of fertilizers.

NITROGEN GAINS AND LOSSES FROM SOILS

Investigations at Rothamsted have shown that a high percentage of the nitrogen that is applied under the climatic conditions of England may neither be absorbed by the crops nor accumulate in the soil. Russell (18) has shown, for example, that about 60% of the total nitrogen that was applied to the Broadbalk plats as manure during the first 47 years of this experiment has been lost from the soil. This

loss was probably caused mainly by biological transformations that are as yet but vaguely understood. The plat that was treated with ammonium sulfate and minerals has sustained a loss of similar magnitude, but in this case leaching was probably more largely responsible for the result. Recently, White and Holben (22) pointed out that more than 50% of the nitrogen that has been applied to certain of the old Pennsylvania plats remains unaccounted for. Unpublished studies strongly indicate that a correspondingly heavy loss of nitrogen takes place under the soil conditions that prevail in southern California.

Considering the total applied nitrogen and that recovered by the crops, there has been a substantial loss of nitrogen from each of the New Jersey (11) tank experiments The factors that are responsible for these losses have not been carefully studied. There is need for additional experiments in which special attention is given such factors as (a) the efficiency of various nitrogen fertilizers, (b) the nitrogen gains and losses sustained by the soil, and (c) the several factors which influence the results. The importance of knowledge concerning these points is attested by the fact that a relatively high percentage of the applied nitrogen remains unaccounted for in every experiment thus far studied, and there is no reason to believe that losses of lesser magnitude take place under practical field conditions. Since nitrogen is a relatively expensive fertilizer element, it is important that we have a clear understanding of the factors which influence its effectiveness.

It is well known that nonsymbiotic fixation of nitrogen may exert an important influence on the nitrogen balance of the soil. White and Holben (22) have concluded that a substantial amount of nitrogen has been fixed by nonsymbiotic organisms in certain of the Pennsylvania plats. On the other hand, Gainey and others have shown that nitrogen fixation by Azotobacter is not active in very acid soil, but that under suitable conditions these organisms may contribute greatly to the nitrogen content of the soil. The conditions which exist in certain places within the inter-mountain section of America seem to be especially favorable to the process of nitrogen fixation by nonsymbiotic organisms. For example, high yields of wheat have been maintained for many years under dry farm conditions at Nephi, Utah (3), without the use of crop rotation or nitrogen fertilization; and the available data indicate that the nitrogen content of the Nephi soil has also been maintained. It is probable, however, that the combination of soil and climatic factors which exist in this locality is exceptional.

There are several phases of the microbiology of nitrogen transformation in soils that need further study. It is especially important that we have a better understanding of the factors which control the gains and losses of nitrogen in soils, and of the relation of nitrogen fertilization and organic materials to these gains and losses. During recent years several investigators have shown that the microbial processes which are involved in the decomposition of plant materials, the formation and decomposition of soluble nitrogen compounds, and the fixation of atmospheric nitrogen are influenced to an im-

portant degree by the carbon-nitrogen ratio of the organic materials of the soil. The specific processes and organisms that are involved in those processes which tend to bring about gaseous evolution of nitrogen from the soil are in need of extended study. As mentioned already our knowledge of the symbiotic fixation of nitrogen by legumes is also inadequate. Obviously, this process is intimately related to the success of leguminous cover cropping and to crop rotations which include legumes. Additional study is needed on the problem presented by the cover crop experiments at the Woburn Experiment Station (5, 6) in which green manuring with mustard has proved a better preparation for cereals than the corresponding growth of vetch.

SUMMARY

1. The results of many plat experiments show that it is possible to increase the yields of crops effectively by the use of nitrogen fertilizer.

2. Reliable information concerning the practical value of nitrogen fertilizers can be obtained only by means of local experiments. The responses of different soils and crops are so varied that sound conclusions of general applicability can not be drawn from a few tests. The use that has been made of field experiments in the United States is inadequate.

3. In certain localities a given nitrogen fertilizer may produce the best results, whereas in another locality or when used on a different crop, some other nitrogenous material may be the more effective. Various factors, such as soil reaction, the influence of small amounts of other elements, and special physiological peculiarities of the crop are probably involved in these variations, but a satisfactory explanation of the results can not now be given.

4. In making practical field experiments due consideration should be given to such factors as seasonal variation, the adequacy of other nutrients, the reaction of the soil, and the time, rate, and method of application. Obviously the experimental technic should be sound.

5. The determination of the specific factors which influence the action and efficiency of the different nitrogen fertilizers, their chemical and physical effect on the soil, and the transformations which both soil nitrogen and that applied as fertilizer undergo in soils require laboratory and controlled conditions.

6. A careful study of the physiological relation between nitrogen, potassium, phosphorus, and the various other elements and constituents that are present in certain nitrogen fertilizers might shed important light on the practical aspects of nitrogen fertilization.

7. The nitrogen nutrition of fruit trees, especially as regards fruit bud formation, the setting and quality of the fruit, and the carbohydrates of the tissues are inadequately understood. The relations of nitrogen to the protein content of cereal grain should also be given further study.

8. The specific factors which influence the transformations of nitrogen in soils have not been sufficiently studied. There is special need for careful study of the factors which control the gains and losses of nitrogen in soils.

9. The relation of nitrogen fertilizers to the yield, composition, and the nutritive value of hay crops and pastures is inadequately understood.

10. The chemical and physical effects which the several nitrogen fertilizers produce on soils are not well understood. There is special importance attached to the relation between these materials and the lime requirements and the pH of the soil.

11. There is need for a thorough investigation of the specific effects which the various nitrogen fertilizers produce on the chemical, physical, and microbiological properties of the soil. The conditions most favorable for the best effects of the several nitrogenous materials should be carefully determined.

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HARD GRAIN TEXTURE OF WHEAT IN MECHANICAL MIXTURES AND IN CROSSES[1]

W. E. BRYAN and E. H. PRESSLEY[2]

The association of hard grain texture in bread wheats with high protein content, and in general with high milling and baking qualities, has attracted the attention of plant breeders and wheat growers for several years. The opinion is rather widely held among wheat growers that the texture of wheats, and particularly that of bread wheats, is determined almost entirely by the climatic conditions under which wheat is grown. This opinion is largely due to the softening of hard-grained varieties in wet seasons or with heavy irrigation, and also to the apparently progressive change to soft texture from year to year of certain hard wheats when grown under irrigation for several years. This paper is a partial report of studies which have been made for the purpose of ascertaining to what extent hard grain texture is permanent in certain pure lines of wheats grown under irrigation.

MECHANICAL MIXTURES

During the past 10 years more than a hundred pure line selections of hard Baart have been tested in comparison with a high yielding, soft strain of Baart. The grain yield and constancy of the hard texture of certain of these hard strains have been discussed in a previous publication (1).[3] In this publication it was shown that nearly all of the hard Baart strains tested were lower in yield than the soft strain with which they were compared. It was also shown that when these hard strains were grown on a fertile soil, such as alfalfa sod, the hard texture of the hard Baart strains was constant from year to year. Among these hard Baart strains, strain No. 34–14–17 over a period of 3 years averaged 8 bushels of grain per acre less than that of soft Baart strain No. 34–16. Since certain hard-grained varieties have appeared to soften progressively, it was thought that such change might have been due to admixtures of high yielding soft strains as was suggested by Freeman (2). In order to test this possibility, certain known mixtures of hard Baart strain No. 34–14–17 and soft Baart strain No. 34–16 were made up on the basis of grain count, as follows: (a) 25% 34–14–17 hard and 75% 34–16 soft; (b) 50%

[1]Contribution from Department of Plant Breeding, Arizona Agricultural Experiment Station, Tucson, Arizona. Received for publication May 16, 1932.
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[3]Reference by number is to "Literature Cited," p. 69.

34-14-17 hard and 50% 34-16 soft; and (c) 75% 34-14-17 hard and 25% 34-16 soft.

Both of the pure strains from which these mixtures were made were also grown, more as a means of determining the amount of uncontrolled mixtures in the cultures which took place in handling than as checks, since the hard strain had maintained its texture for 3 years under irrigation. These mixtures were made up and planted for the first time in the fall of 1924. Table 1 shows the results obtained by years in percentages of hard grains in the three mixtures in comparison with the pure races for a period of 6 years.

TABLE 1.—*Progressive change in percentages of hard grains and soft grains in three mixtures of differdnt proportions of hard- and soft-grained strains of Early Baart wheat in comparison with the pure strains used as a check.*

Initial percentage of hard grains	Percentage of hard grains					
	1925	1926	1927	1928	1929	1930
0	0.0	1.0	1.2	1.2	1.0	1.0
25	20.0	17.0	15.0	9.4	7.8	2.3
50	46.5	39.0	31.4	21.6	24.7	—*
75	72.1	64.0	53.8	44.5	35.2	16.8
100	100.0	98.7	97.8	94.0	96.6	90.0

*Seed lost, not planted.

Each mixture and the two pure races were grown in single plat rows each 600 feet long and 7 inches apart. They were grown under the same field conditions as other field plats of the same size and were irrigated and handled in the same way, except that they were not replicated. In the laboratory the total amount of grain from each plat was thoroughly mixed and the average percentage of hard grains was determined from four 500-grain samples. An examination of Table 1 shows that there is a steady decline in the percentage of hard grains in all three of the mixtures with the exception of the 50-50 mixture in the crop of 1929. This apparent gain in hard grains of about 3% for this particular season must have been due to inadequate sampling. In the crop of 1926, about 1.5% of soft grains occurred in the hard strain, which is thought to be due to a mixture from an adjacent strain of soft Baart. The heads of these plants were harvested by means of hand labor, and although great care was taken to prevent mixing, an occasional head may have been taken from another sort. In the same year, and presumably in the same way, about 1% of hard grains occurred in the soft check.

The changes in the percentages of hard and soft grains in these mixtures through a period of 6 years indicate that the average yield per plant in number of grains of the soft strain is greater than that of the hard strain. Obviously, this greater yield per plant in number of grains can take place either by a greater number of heads per plant, or by a greater number of grains per head, or both.

Grantham (3), Harlan (4), and Clark (5) have shown that tillering is positively correlated with yield in bushels per acre. As mentioned above, the hard Baart strain 34-14-17 is known to be a lower yielder

when planted separately than soft strain 34–16. It was thought therefore, that the increases in the percentages of soft grains in these mixtures might be due to the production of a larger number of heads per plant in the soft strain. In order to test this, the two pure strains used in these mixtures were grown separately in alternate rows 3 inches apart, and the plants of each strain spaced 3 inches apart in the row. In comparing the number of heads per plant of the two strains, only those plants with the same number of plants immediately surrounding them were used, since the stand was not perfect. Table 2 shows the relative tendencies of the soft and hard strains to increase the number of heads per plant according to the reduction in the number of plants immediately surrounding each plant included in the comparison.

TABLE 2.—*Distribution of number of heads per plant with varying space of a hard and a soft strain of Early Baart wheat.*

No. of plants surrounding	8	7	6	5	4
Average No. heads per plant, soft strain 34–16 (571 plants)	2.32	2.46	2.44	2.71	3.16
Average No. heads per plant, hard strain 34–14-17 (471 plants)	2.12	2.16	2 43	2.13	2.50

In Table 2 it is seen that in a full stand as these strains were grown, that is, eight plants immediately surrounding any given plant, the average number of heads per plant for the soft strain (34–16) is 2.32; that for the hard strain (34–14–17) with the same stand 2.12, or 9.4% more heads per plant for the soft strain than for the hard strain. Where the stand was reduced so that only four plants immediately surrounded any given plant, the soft strain produced an average of 3.16 heads per plant and the hard strain only 2.50 heads per plant. This is 26.4% increase in number of heads per plant for the soft strain over the hard. These figures show that the soft strain not only produces more heads per plant with close spacing than the hard strain, but that as the amount of space per plant increases, the soft strain produces proportionately still more heads per plant than does the hard strain. Consequently, in the more or less irregular spacing of commercial planting such as was used with the above mixtures, soft-grained plants will use extra space to better advantage in the way of increase than will plants of the hard strain.

It is also desirable to ascertain the distribution of the number of heads per plant and the number of grains per plant when the spacing is constant and the same for both strains. Table 3 shows such distributions for the perfect stand, that is, each plant immediately surrounded by eight others.

The most striking difference between the distributions shown in Table 3 is the high percentage of three-headed plants in the soft strain 34–16. It will also be observed that for a given number of heads per plant the number of grains per plant is approximately the same in both strains. Therefore, the number of grains produced by

each of these strains in a mixed population consisting of these two strains will be proportional to the number of heads produced by each. On this basis, as calculated from the heads-per-plant distribution

TABLE 3.—*Distribution of number of heads per plant and grains per plant with a constant spacing (3 x 3 inches) of a hard and a soft strain of Early Baart wheat.*

Pure strain No.	Percentage distribution			Grains per plant		
	3 heads	2 heads	1 head	3 heads	2 heads	1 head
34-16, soft (194 plants)	50	32	18	54	35	16
34-14-17, hard (145 plants)	37	36	27	58	38	19

of Table 3, any mixture of these two strains with this spacing (3 x 3 inches) will give an annual increase of soft grains over the hard of 10.4%. As grown in the field with 7 inches between the drill rows (the spacing of the mixtures reported in Table 1), the gain of the soft grains over the hard would be much greater. (See Table 2.) It appears, therefore, that the difference in tillering or number of heads per plant of the soft and hard strains accounts in large part for the gain of the soft strain over the hard in mixtures between them.

It is not the intention of the writers to draw any general conclusions regarding the connection between hard texture and tillering in wheat, but simply to show the mechanism through which the differential seed increase of these two strains actually takes place.

HYBRIDIZATION

In order to study the segregation of the hard grain texture of hard Baart wheat, hard Baart strain No. 34-14-32 was crossed with pure line No. 103 of Sonora in the spring of 1927. The texture of the Sonora grain is very soft and is never glassy, even when grown with a scanty water supply as in dry farming regions. Sonora also differs from hard Baart in a number of plant characters which are of some assistance in studying the filial generations.

Five F_1 seeds were obtained using Sonora as the female parent. The texture of these F_1 seeds was apparently as soft as Sonora seeds which had been self fertilized. Also it has been determined from crosses made at a later date that hard Baart flowers pollinated with Sonora pollen produce grains as hard as those produced by self-pollinated hard Baart flowers. Apparently, therefore, xenia does not affect the expression of texture in these crosses. The five F_1 plants produced hard and soft grains as shown in Table 4.

TABLE 4.—*Segregation in F_2 of hard and soft grain textures in a cross between soft Sonora and hard Baart wheats.*

Plant No.	Number of soft grains	Number of hard grains
1.	131	130
2.	127	134
3.	143	128
4.	79	108
5.	94	101

In this classification a grain was classed as hard if it was appreciably harder than the Sonora grain. This method of classing is rather unsatisfactory, but since every gradation of hardness within the limits of the parents was present in a plant segregating for hard and soft texture, the isolation of intermediate classes with definite limits was impossible. On this basis of selection, 541 F_2 plants were grown from selected soft grains of F_1 plants, and 562 F_2 plants from selected hard grains of the same origin. Table 5 shows the type of segregation which occurred in the offspring of these selections.

TABLE 5.—*Offspring of selected hard and selected soft F_2 grains of a cross between soft Sonora and hard Baart wheats.*

Texture of F_2 grains planted	No. plants with hard grains only	No. plants with hard and soft grains	No. plants with soft grains only
Hard.................. ..	254	308	0
Soft.................... .	0	205	336

The following F_3 progenies were grown: (a) Sixty-one progenies from plants each having soft seeds only. All of the plants in each of these progenies produced only soft grains. (b) Sixty-seven progenies from plants each having hard seeds only. Forty-three of these progenies each produced hard-grained plants only, while the remaining 24 progenies each segregated for the hard and soft textures.

That definite segregation for texture occurred in the gametes of the F_1 plants is shown by the appearance of both types of texture in the F_2 seeds of the F_1 plants, as shown in Table 4. This fact is confirmed by the results obtained in the F_3 seed generation (Table 5) in which selected hard grains gave plants some of which produced hard grains only and some both hard and soft grains, but *none with soft grains only*. Also, selected soft seed from the F_2 seed generation gave plants some of which produced soft seed only and some both soft and hard grains, but *none with hard grains only*. It will also be observed from Table 5 that selected F_2 hard seed gave a greater proportion of segregating plants than did the selected F_2 soft seed. Furthermore, all progenies originating from plants having soft grains only were entirely soft, but of those originating from plants having hard seeds only, approximately one-third of them were found to be segregating for texture. Therefore, while it is clear that definite segregation for texture has occurred, the number of factors involved is not so evident. It is probable, however, that a single main factor separates the two types of texture and that numerous modifying factors are also present which obscure the three expected classes in the heterozygote where dominance is absent.

CONCLUSIONS

The differences in yielding ability of the strains composing commercial varieties of self-pollinated crops may be sufficient to cause the elimination of the low yielding strains and thus give the variety the appearance of more or less rapid change in any quality connected with the low yielding strains. Hard-textured strains appear

to be eliminated from bread wheat varieties in this way when high yielding soft sorts are present.

Hard grain texture is a heritable character capable of combination with other economic characters in wheat breeding.

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EFFECT OF REDUCED OXYGEN PRESSURE ON RICE GERMINATION[1]

JENKIN W. JONES[2]

The control of barnyard grass (*Echinochloa crusgalli*) in the rice fields of California is based upon continuous submergence of the land, and since this reduces the oxygen pressure for seed germination, the two factors, continuous submergence and reduced oxygen pressure, are directly associated in the control of weeds. Seeds of barnyard grass germinate under water; however, the seedlings grow more slowly under water than do rice seedlings and in this way the weeds are controlled.

A large acreage of the rice land in California is so foul with barnyard grass and varieties that special irrigation methods have been developed to control these weeds.

It is practically impossible to grow satisfactory rice crops on foul land by the method of irrigation formerly used, which consisted of flooding and draining the land after seeding and at intervals of about 10 days until 30 days after the rice had emerged. The land was then submerged about 6 inches deep and the water was held at this depth until the fields were drained preceding the harvest. This method of irrigation provided almost ideal conditions for the growth and reproduction of barnyard grasses.

The method of irrigation now used on foul land is as follows: A fairly good seedbed is prepared and submerged shallow. The rice is then sown broadcast in the water. An alternative method is to sow broadcast on the surface of the dry soil, which is then submerged. The land is continuously submerged after seeding to an average

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the California Agricultural Experiment Station. Received for publication May 27, 1932.

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depth of about 6 inches until the rice is mature enough to be drained for harvest. Heavier rates of seeding are required to obtain good stands when rice is sown either in the water or on the dry soil surface and held continuously submerged thereafter than when it is grown by alternate flooding and draining until after the rice has emerged.

Seed rice germinates under water on continuously submerged land and the young seedlings stretch upward to the surface of the water, while the seedlings of most forms of barnyard grass are unable to emerge through about 6 inches of water. In this way these weeds are controlled.

Rice seedlings from seed germinated under water differ in certain respects from seedlings obtained from seed that is covered with soil and alternately flooded and drained during early germination and growth. Seedlings from submerged seed elongate rapidly until they reach the surface of the water. The leaves are long, narrow, and delicate, and the roots are poorly developed. The seedlings at first are not firmly anchored in the soil. Seedlings obtained from drilled rice alternately flooded and drained have relatively short, wide, deep green leaves and an extensive root system. Such seedlings are well anchored in the soil even when quite young.

Better stands of rice usually are obtained by continuous submergence early in the spring when the temperatures of the atmosphere and water are lower than they are later in the season. High temperatures are favorable to more rapid growth of algae, decomposition of organic matter, formation of scum, and loss of oxygen from the water. Algae and scum shade the plants, weaken them, and often prevent them from emerging through the water. A certain amount of oxygen apparently is essential for normal root development and chlorophyll formation in rice seedlings.

Part of the seed sown broadcast on the surface of the soil is covered by slacked clods when the land is submerged. Such seeds, covered with soil and water, often fail to germinate completely, producing only plumules, and the radicles and crown roots fail to develop.

REVIEW OF LITERATURE

Akemine (2)[3] found that rough rice and brown rice germinate equally well in water and in air. The plumule, after its appearance, grows much more rapidly in water than in air, while the radicle and crown roots grow much slower in water than in air. As a result of various experiments on the germination of rice, Akemine (1) concluded that under normal conditions in the germination of a healthy rice kernel the plumule appears first, whereas in an abnormally dry medium the radicle appears first.

Nagai (5) observed that rice can be germinated at an extremely low oxygen pressure, but the development of the radicle is totally inhibited. In such cases a supply of oxygen initiates the development of the radicle.

Hutchins (3) found that rice germinated at the lowest oxygen pressure of any crop tested in his experiments.

[3]Reference by number is to "Literature Cited," p. 81.

The quantity of catalase in the dry seeds of rice, according to Morinaga (4), is about one-tenth as great as that of wheat, barley, oats, and rye. He states that oxygen retards the elongation of the plumule and accelerates the development of the radicle, whereas a lack of oxygen has exactly the reverse effect. Sasaki (6) observed in rice seeds germinating at a reduced air pressure that the radicle developed very poorly and in some cases did not emerge at all.

Yokoi (8) studied the development of the plumule and radicle of rice seed germinating in free water and in sand ranging in moisture content from 7.5% to above the water-holding capacity, or 31.5%. He calculated the growth ratio of plumule to radicle in millimeters from one to nine days, inclusive. The data for the fourth and eighth days are given in the following tabulation by Yokoi:

Percentage of water in sand	Ratio	
	Fourth day Plumule: Radicle	Eighth day Plumule: Radicle
In water	1:0.32	1:0.80
Excess of water in sand	——	1:0.80
30	1:1.57	1:2.22
27	1:1.58	1:1.59
24	1:3.39	1:2.28
20	1:1.66	1:2.54
18	1:1.88	1:2.73
15	1:2.87	1:3.92
12	1:4.51	1:4.54
7.5	1:14.14	1:5.50

When there is an excess of water in the germinating medium the plumules develop before the radicles, and "on the contrary, when the quantity of water contained in the sand is scanty (from 15 to 7.5%) the radicle develops before the plumule."

Takahashi (7) found that rice seed was able to germinate in plain water in the absence of air He explains that rice grows naturally in places where germination must occur in the presence of very little oxygen. In the experiment, however, growth seemed to stop when the plumule reached a length of 3 cm.

GERMINATION OF DRILLED RICE CONTINUOUSLY SUBMERGED

A plat of Caloro rice was sown with a grain drill about 1½ inches deep on May 6, 1925. On May 11 this plat was irrigated and drained, but owing to seepage from a near-by irrigation ditch, it was not possible to remove all water. On May 27, 207 seeds that had been buried in the soil and water were dug up from a drill furrow. Except for an occasional plant the seed of which apparently had not been covered with soil at seeding time, no plants emerged where the water stood. Of the 207 seeds dug up, 70% had failed to germinate, 27.05% had produced plumules but no radicles, and 2.90% had produced plumules and poorly developed radicles. In those seeds that produced plumules only, the plumules were long, often more than an inch, colorless, and unable to emerge to the surface of the soil. In a

second plat of Caloro (drilled and continuously submerged) 133 seeds were dug up. Of this number 57.89% had failed to germinate, 37.59% had produced plumules only, and 4.51% had produced both plumules and radicles. Likewise, from a drilled plat of Selection 178, that had been submerged since May 11, 130 seeds were dug up. Of this number 74.62% had failed to germinate, 24.62% had produced plumules but no radicles, while only one seed had both a plumule and a radicle.

These observations concerning the germination of continuously submerged drilled rice show that an unusually high percentage of the seed failed to produce both plumules and radicles. The failure of the seed to show a normal[4] germination apparently is associated with a reduced supply of oxygen.

GERMINATION EXPERIMENTS IN POTS

In 1925, 1928, and 1929 experiments were conducted in small paper pots to determine the effect of continuous submergence and depth of seeding on germination of rice seed. Each year seed was sown on the surface of the soil and ½, 1, 1½, 2, and 2½ inches deep, respectively. Fifteen well-matured seeds of the Caloro variety were sown in each pot. Each depth of seeding was replicated five times. All pots, as the seed was sown, were placed in a shallow box. This box, containing the six series of pots representing each depth of seeding, was then placed in a field plat in such a manner that the surface of the soil in each pot was submerged about 4 inches.

The seed sown on the surface of the soil was not covered. This method is therefore comparable to seeding in the water.

In 1925, the pots were placed in the water on May 19; in 1928, on May 31; and in 1929, on May 1. In 1925, the counts on germination were made on June 17, in 1928 on June 28, and in 1929 on May 21. In determining the percentage of germination the soil was carefully washed from each pot, and the seed was collected on a fine-mesh wire screen. In this way all seed was recovered each year, except that from the surface seeding in 1925.

In Table 1 are shown the number of seedlings that emerged, the number of seeds that produced plumules only, the number of seeds that failed to germinate, and the total in each group for the 3 years. In this period 157 seeds from the surface seeding, 45 from the ½-inch seeding depth, and 6 from the 1-inch seeding depth produced seedlings, whereas none of the seed sown 1½, 2, and 2½ inches deep produced seedlings. The seed sown on the surface of the soil either produced seedlings or failed to germinate. The number of seeds that failed to germinate materially increased from the surface to the 2-inch depth of seeding, while the absolute number of seeds that produced plumules only was greater from the ½-inch than from the 2-inch depth of seeding. The relative number in proportion to total germination was much less. More seed produced plumules only and fewer seeds failed to germinate in the 2½-inch depth of seeding than

[4]The expression "normal germination" as used in this paper means the development of both plumules and radicles in the germinating seed.

Table 1.—*Number of seeds sown at different depths that produced seedlings, or plumules only, or that failed to germinate in the years stated at Biggs, Calif.*

Depth of seeding	Seedlings			Plumules only			Failed to germinate			Total for 3-year period		
	1925	1928	1929	1925	1928	1929	1925	1928	1929	Seedlings	Plumules only	Failed to germinate
Surface....	40*	70	47	0	0	0	11	5	28	157	0	44
½ inch....	18	19	8	14	22	22	43	34	45	45	58	122
1 inch.	4	2	0	19	23	9	52	50	66	6	51	168
1½ inches.	0	0	0	8	19	11	67	56	64	0	38	187
2 inches....	0	0	0	1	14	5	74	61	70	0	20	205
2½ inches .	0	0	0	4	7	14	71	68	61	0	25	200

*Twenty-four seeds were washed out of the surface pots and lost in 1925

Table 2.—*Percentage of seeds sown at different depths that produced seedlings, o. plumules only, or that failed to germinate in the years stated at Biggs, Calif.*

Depth of seeding	Seedlings			Plumules only			Failed to germinate			Average percentage		
	1925	1928	1929	1925	1928	1929	1925	1928	1929	Seedlings	Plumules only	Failed to germinate
Surface....	78.43	93.33	62.67	0.00	0.00	0.00	21.57	6.67	37.33	78.14	0.00	21.86
½ inch.....	24.00	25.34	10.67	18.67	29.33	29.33	57.33	45.33	60.00	20.00	25.78	54.22
1 inch......	5.33	2.66	0.00	25.33	30.67	12.00	69.34	66.67	88 00	2.66	22.67	74.67
1½ inches .	0.00	0.00	0.00	10.66	25.33	14.67	89.34	74.67	85.33	0.00	16.89	83.11
2 inches....	0.00	0.00	0.00	1.33	18.67	6.67	98.67	81.33	93.33	0.00	8.89	91.11
2½ inches..	0.00	0.00	0.00	5.33	9.33	18.67	94.67	90.67	81.33	0.00	11 11	88.89

in the 2-inch depth. This probably was because the seed sown 2½ inches deep was near the bottom of the pots and, therefore, closer to the water (oxygen) surrounding the pots than those sown at the 2-inch depth.

In Table 2 is shown the percentage of the seed sown at different depths that produced seedlings, or plumules only, or that failed to germinate for each year, and the average for the 3-year period. In this period 78.14% of the seed sown on the surface of the soil, 20% of that sown ½ inch deep, and 2.66% of that sown 1 inch deep produced seedlings. None of the seed sown on the surface of the soil produced plumules only. The number of seeds sown from ½ to 2½ inches deep that produced plumules only varied from 8.89% for the 2-inch depth to 25.78% for the ½-inch depth of seeding. For the three years the percentage of seed that failed to germinate ranged from 21.86% for the surface seeding to 91.11% for the seed sown 2 inches deep. This marked decrease in normal germination of submerged rice seed, with increased depths of seeding, apparently is associated with a reduced supply of oxygen under such conditions.

RESULTS AT THE ARLINGTON EXPERIMENT FARM[6]

LABORATORY EXPERIMENTS

Germination experiments were conducted in laboratory and greenhouse at the Arlington Experiment Farm, Rosslyn, Va., in earthen pots. A layer of gravel was placed in the bottom of the pots and a layer of sand above the gravel. An inverted cone of fine-mesh copper wire was placed in position over the sand in each pot and cemented. On February 1, 1930, as the pots were being filled with a heavy clay soil, 100 seeds of the Caloro variety were sown on the surface of the soil ½, 1, 1½, 2, and 2½ inches deep, respectively. The soil in the pots was continuously submerged about 4 inches deep after seeding. One pot was connected through an opening in the bottom with an oxygen pressure tank and oxygen was continuously forced through the soil. The other pot was treated in the same manner, except that no oxygen was forced into the soil.

The soil used in these pots was practically free of organic matter and was so badly run together after submergence that it was impossible to get a satisfactory penetration of the oxygen through the soil. The oxygen bubbled through the water mostly in one place. It appears that only a small part of the soil and seed in the pot actually came into contact with the oxygen as it passed upward through the soil. In the pot through which oxygen was forced some of the seed sown on the surface of the soil was covered and lost. Therefore, all seed sown was not recovered when counts on germination were made on February 21. In the room where this test was made the temperature ranged from about 60° to 70°F, which is too low for a maximum germination of rice.

The number of seeds that produced seedlings, or plumules only, or

[6]The writer is indebted to M. N. Pope, agronomist in barley investigations, Division of Cereal Crops and Diseases, for assistance in setting up this experiment at the Arlington Experiment Farm and for suggestions and equipment used.

that failed to germinate, and the percentage in each case, are shown in Table 3. In the control pot only the seed sown on the surface of the soil produced a fairly large number of seedlings. In the pot receiving oxygen more seedlings (plumules and radicles) were obtained from the seed sown 2½ inches deep than from the surface seeding. The distribution of oxygen just above the sand layer was apparently fairly good, but farther up in the pot the oxygen appears to have escaped rapidly with little or no effect on the germination of the seed. It was observed that the oxygen escaped from the water mostly around the edges of the pot. Apparently the oxygen did not penetrate the mass of soil. A wire probe was pushed into the soil in several places in an attempt to diffuse the oxygen throughout the soil, but the oxygen continued to follow the original lines of least resistance. The effect of the oxygen, therefore, was confined largely to the seed sown 2½ inches deep, or just above the layers of gravel and sand near the bottom of the pot.

In the control pot more seed produced plumules only at all depths of seeding than in the pot receiving oxygen. However, more seed failed to germinate at all depths in the pot receiving oxygen than in the control pot, except for the seed sown on the surface of the soil. Twenty per cent of the seed sown 2½ inches deep in the pot through which oxygen was forced produced seedlings (plumules and radicles), while no seedlings were produced at this depth in the control pot. It appears that this difference was due to the beneficial effects of the oxygen on germination and the growth of the radicle, for in the pot experiments conducted for 3 years at Biggs, Calif., no seedlings were obtained from seed sown more than 1 inch deep.

GREENHOUSE EXPERIMENTS

Germination experiments were conducted in earthen pots in a greenhouse at the Arlington Experiment Farm, Rosslyn, Va. A layer of gravel was placed in the bottom of the pots and a layer of sand above the gravel. A fine-mesh wire screen was placed in position over the sand in each pot. On January 8, 1932, as the pots were being filled with Stockton clay adobe soil, a typical soil in California on which rice is grown, 100 seeds of the Caloro variety were sown on the surface of the soil, ½, 1, 1½, 2, and 2½ inches deep, respectively. After seeding, the soil in the pots was continuously submerged about an inch deep. One pot was connected through an opening in the bottom with an oxygen pressure tank, and oxygen was continuously forced through the soil. The other pot was treated in the same manner, except that no oxygen was forced into the soil.

As in the previous experiment the oxygen bubbled through the water largely in one place near the edge of the pot. It appears that only a small part of the seed actually came into contact with the oxygen as it passed upward through the soil.

The temperature of the greenhouse in which this experiment was conducted ranged from 70° to 75°F at night and 80°F or higher in the day time. These temperatures apparently were too high for normal germination in water because only 2.08% of the seed sown in the

TABLE 3.—*Number of seeds sown at different depths that produced seedlings, or plumules only, or that failed to germinate, and the percentage in each case, at the Arlington Experiment Farm, Rosslyn, Va., 1930.*

Depth of seeding	Seedlings*		Plumules only		Failed to germinate		Seedlings, %		Plumules only, %		Failed to germinate, %	
	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen
Surface....	48	18	33	17	19	10	48.00	40.00	33.00	37.78	19.00	22.22
½ inch.....	1†	6	61	45	35	56	1.03	5.60	62.89	42.06	36.08	52.34
1 inch.....	1†	1†	65	41	33	70	1.01	0.89	65.66	36.61	33.33	62.50
1½ inches..	0	1†	56	24	40	85	0.00	0.91	58.33	21.82	41.67	77.27
2 inches....	0	0	65	27	31	73	0.00	0.00	67.71	27.00	32.29	73.00
2½ inches..	0	20	62	30	38	50	0.00	20.00	62.00	30.00	38.00	50.00

*Plumules and radicles.

†Plants near edge of pots.

water produced plumules and radicles, whereas at Biggs, California, under like conditions, but at lower mean temperatures, an average of 78.14% of the seed sown in the water produced plumules and radicles. It is difficult to obtain good stands of rice in California when the seed is continuously submerged late in the spring and the temperatures are high. This result appears to be associated in part with a shortage of dissolved oxygen in the water at high temperatures.

The number of seeds that produced seedlings, or plumules only, or that failed to germinate, and the percentage in each case, are shown in Table 4. In the control pot only 4% of the seed sown ½ inch deep produced plumules and radicles, and none of the seed sown 1, 1½, 2, and 2½ inches deep produced seedlings (plumules and radicles). In the pot receiving oxygen, 31% of the seed sown ½ inch, 1% of the seed sown 1½ inches, 13% of the seed sown 2 inches, and 4% of the seed sown 2½ inches deep produced seedlings. In this case it appears that the oxygen was distinctly beneficial to the germination of the seed sown ½ inch, 2, and 2½ inches deep, respectively.

In order to get a better distribution of the oxygen through the pot white quartz sand instead of soil was used in one experiment. In this experiment seed was sown in the water and 1, 2, and 3 inches deep, respectively. This experiment was carried on in a greenhouse in the same manner and at the same temperatures as in the experiment just reported.

The number of seeds that produced seedlings, or plumules only, or that failed to germinate, and the percentage in each case, are shown in Table 5. In the control pot 15.63% of the seed sown in the water on the surface of the sand produced seedlings. However, none of the seed sown 1, 2, and 3 inches deep, respectively, produced seedlings. In the pot through which oxygen was forced 93.94% of the seed sown in the water, 54.37% of the seed sown 1 inch deep, 64.36% of the seed sown 2 inches deep, and 46% of the seed sown 3 inches deep produced seedlings. It is very evident in this case that oxygen was decidedly beneficial to the development of radicles in the germinating seeds.

Tap water is said to contain less dissolved oxygen than open streams. The water used in the irrigation of rice at Biggs, California, is diverted from the Feather River, a cold mountain stream. The difference in temperature between the tap water used in the greenhouse and the river water used in the field is probably largely responsible for the low percentage of normal germination from seed sown in the water in the greenhouse as compared with that obtained in the field. High temperatures are favorable for normal germination provided sufficient oxygen is available in the water to initiate development of the radicle. This fact is evident from the results of the surface seeding on sand. In the control pot, 15.63% of the seed produced seedlings, whereas in the pot receiving oxygen 93.94% of the seed produced seedlings.

It was observed in these experiments that, as a rule, the length of the plumules in the seed that produced plumules only decreased with increased depth of seeding. The plumules of the seedlings produced in contact with oxygen were much larger in diameter than those pro-

TABLE 4.—*Number of seeds sown at different depths in Stockton clay adobe soil that produced seedlings, or plumules only, or that failed to germinate, and the percentage in each case, at the Arlington Experiment Farm, Rosslyn, Va., 1932.*

Depth of seeding	Seedlings		Plumules only		Failed to germinate		Seedlings, %		Plumules only, %		Failed to germinate, %	
	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen
Surface....	2	—	69	—	25	—	2.08	—	71.75	—	26.04	—
½ inch.....	4	31	59	23	37	46	4.00	31.00	59.00	23.00	37.00	46.00
1 inch......	0	0	55	52	45	42	0.00	0.00	55.00	55.32	45.00	44.68
1½ inches..	0	1	50	62	50	37	0.00	1.00	50.00	62.00	50.00	37.00
2 inches....	0	13	61	43	39	44	0.00	13.00	61.00	43.00	39.00	44.00
2½ inches..	0	4	47	50	53	46	0.00	4.00	47.00	50.00	53.00	46.00

TABLE 5.—*Number of seeds sown at different depths in sand that produced seedlings, or plumules only, or that failed to germinate, and the percentage in each case, at the Arlington Experiment Farm, Rosslyn, Va., 1932.*

Depth of seeding	Seedlings		Plumules only		Failed to germinate		Seedlings, %		Plumules only, %		Failed to germinate, %	
	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen	No oxygen	Oxygen
Surface.....	15	93	60	4	21	2	15.63	93.94	62.50	4.04	21.87	2.02
1 inch......	0	56	88	40	14	7	0.00	54.37	86.28	38 83	13.72	6.80
2 inches....	0	65	94	33	6	3	0.00	64.36	94.00	32.67	6.00	2.97
3 inches....	0	46	90	53	11	1	0.00	46.00	89.11	53 00	10.89	1.00

duced at low oxygen pressure. The plumules of seed that produced plumules only were slender and white, while those of seed that produced plumules and radicles in contact with oxygen were thick and developed chlorophyll at an early stage. Some of the plumules developed by seed sown 2 and 3 inches deep in the sand in which oxygen was forced curled downward toward the source of oxygen. The seedlings in contact with oxygen produced a larger number of roots and they were longer than the roots of seedlings obtained at a reduced oxygen pressure.

Fig. 1 shows the effect of continuous submergence and depth of seeding on the germination of rice. The seed sown 1-inch deep lacked sufficient oxygen to initiate root growth, while the seed sown 2½ inches deep in the pot into which oxygen was forced produced root growth. The development of roots in the latter case was largely due to the presence of oxygen. No seedlings were obtained from seed sown more than 1 inch deep in the 3-year period under field conditions at Biggs.

DISCUSSION

Germination tests with rice sown at various depths under field conditions and continuously submerged indicate that a very thin layer of soil above the seed reduces the oxygen pressure to a point at which normal germination does not take place. A layer of soil ½ inch thick reduced the number of seedlings obtained by 58.11%, and a layer of soil 1 inch thick reduced the number of seedlings obtained by 75.45%. Of the seed sown 1½, 2, and 2½ inches deep none produced seedlings. A small percentage, however, produced plumules only. Most of the seed sown at these depths failed to germinate and rotted. The fact that a large percentage of the seed sown ½ and 1 inch deep produced plumules only indicates that at these depths there was insufficient available oxygen to initiate the development of the radicle and crown roots. At a depth of 1½, 2, and 2½ inches the percentage of seed that produced plumules only rapidly decreased with the increased depth of seeding, and the number of seeds that failed to germinate increased materially.

No information was obtained in the experiments on the supply of oxygen actually present at the various depths of seeding. However, the large number of seeds that produced plumules only, the bleached color of the plumules, the failure of the radicle to develop, and the failure of much of the seed to germinate when covered with soil and water are characteristics that have been described (7) in germination tests of rice as being due to a reduced supply of oxygen. The low percentage of germination of seed covered with soil and water reported in this paper was apparently due to a reduced oxygen pressure.

The results on germination under water show that where land is to be continuously submerged, seeding in the water is a better practice than seeding on the dry soil before submergence. A good deal of the seed sown before the land is submerged is covered by slacked clods from ½ to 1 inch deep or more, depending upon the condition of the seedbed. The remainder of the seed is left on the surface of the soil. It is more expensive to sow rice in water than on dry ground, but the fact that better stands of rice normally are obtained justifies the

additional expense. Then, too, less seed is required to obtain productive stands by seeding in the water than by seeding on dry ground. On rough cloddy seedbeds in particular it is much safer to sow in the water than on dry ground.

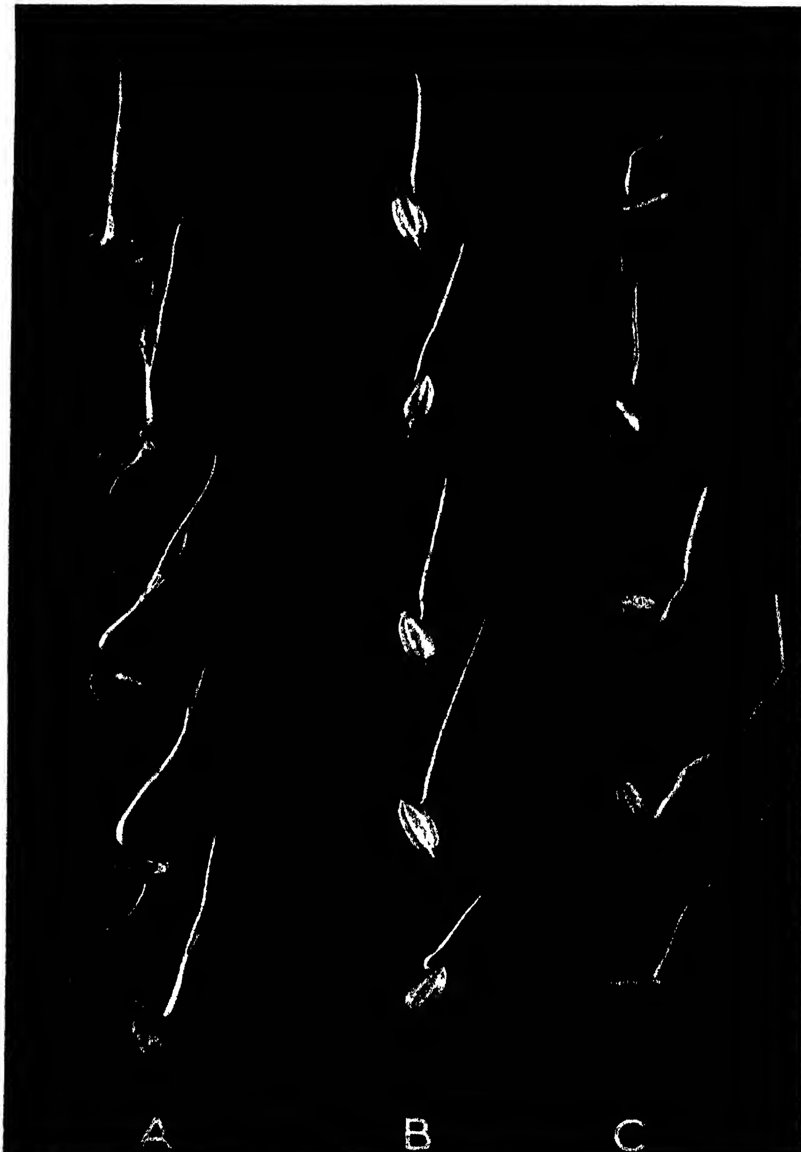

FIG. 1.—Rice seedlings showing effect of continuous submergence and depth of seeding on germination. A, surface seeding; B, 1-inch depth (lack of oxygen); C, 2½ inches deep (with oxygen).

SUMMARY

In the 3 years during which this work was conducted in the field rice sown on the surface of the soil, ½ inch, and 1 inch deep, then continuously submerged, produced an average of 78.14, 20.00, and 2.66% of seedlings, respectively. No seedlings were obtained from seed sown 1½, 2, or 2½ inches deep and continuously submerged either in the field or in pots in the greenhouse, except when oxygen was forced into the soil

All seed sown on the surface of the soil either germinated and produced normal seedlings or failed to germinate Of the seed sown ½ inch deep in the field an average of 25 78% produced plumules only With increased depth of seeding, however, the percentage of seed that produced plumules only decreased and the percentage of seed that failed to germinate increased materially

The results presented indicate that when continuously submerged a ½-inch layer of Stockton clay adobe soil materially reduced the oxygen pressure and a layer 1 inch or more in depth reduced the oxygen pressure to a point at which normal germination did not occur Apparently there was insufficient oxygen under such conditions to initiate growth of the radicle. These results indicate that seeding in the water (surface seeding in these experiments) is the best practice when rice is grown by continuous submergence.

The results presented from germination in pots into which oxygen was forced, especially in sand, indicate that a deficiency of oxygen is probably the principal factor causing a lack of normal germination in rice seed sown at various depths and continuously submerged with water. The development of the radicle is initiated by a suitable supply of oxygen.

Early seeding of rice is preferable to late seeding because temperatures of the atmosphere and water are lower early in the spring than they are late in the spring, and more oxygen is dissolved in water at low temperatures than at high temperatures. The dissolved oxygen at the lower temperatures results in a larger percentage of seedlings than can be obtained at higher temperatures.

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NOTES

CONTROL OF WEEDS IN LAWNS WITH CALCIUM CYANAMID

Many lawns and pastures are infested with weeds and a treatment that would control them, and at the same time supply nitrogen that is much needed, would be very desirable. The purpose of this note is to report some results obtained with the use of calcium cyanamid as an herbicide on lawns.

Bermuda grass (*Cynodon Dactylon* (L.) Pers.) is the chief lawn grass of the southern states. Occasionally, Dallis grass (*Paspalum dilatatum* Poir.), carpet grass (*Axonopus compressus* (Siv.) Beauv.), centipede grass (*Eremochloa ophiuroides* (Munro) Hack.), and other grasses are used. Lawns frequently appear unsightly due to infestation by winter annual weeds which persist into the spring. The more common of these weeds are the chickweeds (*Cerastium viscosum* L., *Stellaria media* (L) Cyrill.), crane's-bill (*Geranium carolinianum* L.), cud-weed (*Gnaphalium purpureum* L.), henbit (*Lamium amplexicaule* L.), peppergrass (*Lepidium virginicum* L.), plantain (*Plantago*, sp.), and wood sorrel (*Oxalis stricta* L.). In the spring, crab grass (*Digitaria sanguinalis* Scop.) sometimes becomes a pest. All of these weeds were in the areas treated with calcium cyanamid in the experiments herein reported.

In February 1932, areas on an established lawn of Bermuda grass were treated with different amounts of calcium cyanamid to determine its effect on the growing weeds and dormant Bermuda grass that were present. The calcium cyanamid was broadcast by hand on the sod at rates varying from 200 to 2,000 pounds per acre. All of the weeds were killed by applications of 800 pounds or more per acre but with smaller amounts some were not destroyed. This was possibly due to the uneven distribution of the material since it was not possible to cover all of the weeds with the smaller applications. A comparison of A and B in Fig. 1 shows the effect of the cyanamid on the weeds. The stimulation of the Bermuda grass, from the nitrogen in the calcium cyanamid, was very marked when growth started in April and continued quite evident throughout the growing season.

In May 1932, after Bermuda grass was growing vigorously, other areas were treated at rates varying by 500-pound increments from 500 to 2,000 pounds per acre to determine the effect of the calcium cyanamid on the active grass and weeds. The areas treated contained some crab grass in addition to other weeds. All of the weeds, including the crab grass, were killed by an application of 1,000 pounds or more per acre. An application of 500 pounds per acre killed most of the weeds. Failure to kill all the weeds was probably due to the uneven distribution of the cyanamid. In all cases the Bermuda grass leaves were burned badly, or entirely killed, but in about 2 weeks the plants had put out new leaves and were growing vigorously. The stimulation from nitrogen was very marked, and the treated areas showed much improvement with respect to growth and freedom from weeds over those untreated.

The cyanamid treatment was used on sods of carpet, Dallis, and centipede grasses with satisfactory results. In all cases the foliage

was burned seriously, but the plants put out new leaves and were soon growing vigorously. All of the grasses treated were perennials.

This treatment might be successfully used in killing annual weeds

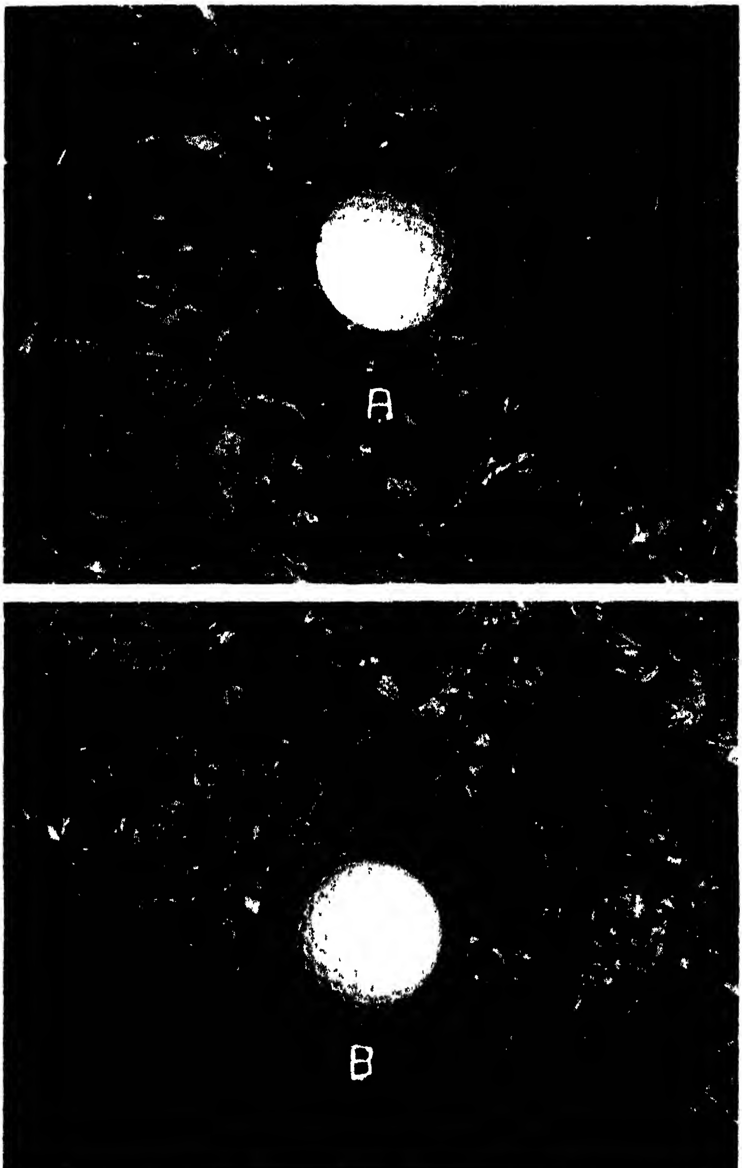

FIG. 1.—A, untreated area in Bermuda grass lawn. B, area treated with 1,600 pounds of cyanamid per acre. The treatment was applied in February 1932, and the photographs made in April of that year.

in pastures. It has been used to kill bitter weed (*Helenium tenuifolium* Nutt.) in preliminary experiments in connection with those reported above. At least it offers an opportunity for study since cyanamid is relatively cheap and the stimulation from the nitrogen may partially compensate for the cost of the treatment. One of the chief difficulties with its use is the method of application. So far as is known there is no machine that will apply the material satisfactorily Further investigations are being made with the use of this material as an herbicide.—D. G. STURKIE, *Department of Agronomy and Soils, Alabama Polytechnic Institute, Auburn, Ala.*

SPECIAL FERTILIZER BOXES FOR PLAT WORK

The commercial equipment furnished with the ordinary beet drills is seldom satisfactory for applying definite amounts of fertilizer to small plats. The difficulty of setting the boxes to apply a definite amount and the difficulty of cleaning the remnants of fertilizer out of the boxes at the ends of the plats, made it impractical to use the ordinary fertilizer boxes for this work at the Michigan State College this last spring. Accordingly, special boxes were built which would deliver the fertilizer at the rate desired and which could also be cleaned quickly when desired. The construction of these boxes was such that the fertilizer application rate could be varied from as low as 50 pounds per acre to as high as 1,000 pounds by relatively small intervals, depending upon the ratio of the sprocket wheels used that operated the mechanism and the opening of the fertilizer feed gate. These boxes, being of limited capacity, are adapted only for plats ranging from 50 to approximately 500 feet in length.

FIG. 1.—Showing the boxes in position on the beet drill. Each box is held by a strap iron stirrup bolted to the rear member of the frame. The boxes were lined up by raising or lowering them in the stirrup, and finally bolting each with two bolts on a side.

While boxes, similar to those shown in Figs. 1 to 3, might not be suitable for all purposes in plat work, modification of the plan followed would greatly increase their scope of usefulness. For plat work that necessitates the placing of the fertilizer in a continuous stream in or near the row, greater accuracy was achieved by using these boxes than had been secured by any other means.

These parts were built from parts obtained from a standard make of grain drill On the original drill these parts were both part of the bottom and the fertilizer feed of a continuous box, but it was found that they could be taken apart and made sectional or each bottom piece and each feed piece could be made part of an individual box Thus, four separate boxes with feed-setting levers were made and placed on the beet drill.

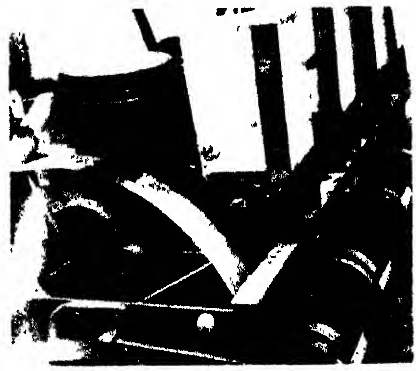

FIG. 2. Showing the sprocket wheel which drives the two left hand boxes It is necessary to secure a large sprocket wheel for this purpose, otherwise the fertilizer would be fed at too fast a rate

The parts that were purchased for the construction of these boxes were 4 bottom plates, 4 turn tables, 4 shed plates, 4 gates, 4 control levers complete, 4 quadrants, 1 drive shaft (later cut in two pieces), 4 turn table drive gears, 4 small gears, 8 bushings to carry square drive shaft or hold small gear in position, and 4 fertilizer feed tubes

FIG. 3.--The fertilizer feed control is through a gate controlled by a lever and a quadrant. One notch on the quadrant corresponds to a much smaller movement on the gate due to the lever working through a reducing gear arrangement. After one or two trials, the lever can be set so that any fertilizer mixture will be carried completely out of the box at the desired rate within a very few inches of the end of the plat.

The parts that were made by hand were 4 stirrups to hold boxes on drill frame and 4 galvanized boxes to hold fertilizer

Since the parts purchased were made to work in a certain relation, one with the other, all that was necessary in the construction of the separate boxes was to construct a box and stirrup that would hold these parts in that relationship. This was done by basing all work on the position of the base plate. Fig. 4 shows the relation of these various parts, and the manner in which the various boxes were fastened to the beet drill.

With a comparatively large number of commercial drills equipped with fertilizer attachments, it should be a relatively simple matter to select a set of parts that would lend themselves readily to the con-

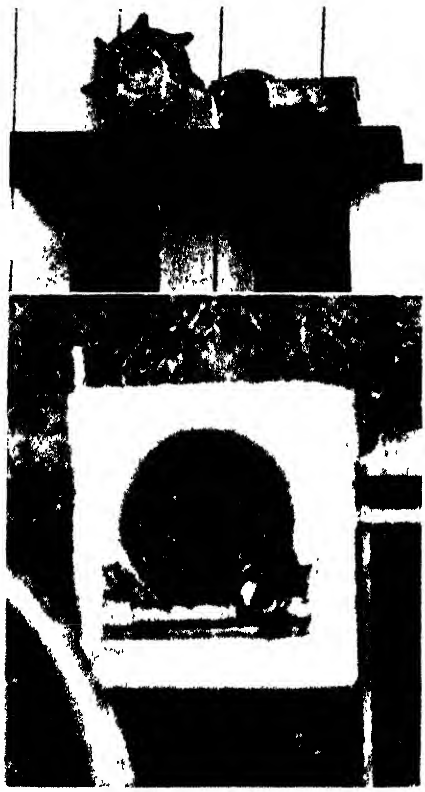

FIG. 4.—The turn table and the shed plate (above) can be removed from the box for cleaning. In order to confine the fertilizer on the turn table, a form (lower) was placed around the turn table and all space outside filled with patching plaster. Only a little sweeping is necessary to insure all the fertilizer being carried out of the box

struction of individual boxes which would permit of rapid and easy cleaning when necessary. Alteration in the design of the galvanized box could be made so that no sweeping at all would be necessary, resulting in even distribution of the fertilizer from the start of drilling and continuing until all of the fertilizer was out of the box.—J. G. LILL, *Division of Sugar Plant Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture.*

BOOK REVIEW

ACKERBAULEHRE (SCIENCE OF AGRONOMY)

By Th Roemer and Fr. Scheffer. Berlin· Paul Parey. VIII + 464 pages, illus. (7 color plates.) 1933 Bound, Rm. 19.80; unbound, Rm. 18.—

In the first chapter, soil fertility is defined and the complexity of the concept is outlined Climate and weather—light, air, water, and heat— are then discussed as factors independently related to the climate Thereafter the interaction of climatic factors leading to climatic types is taken up. "Weather" is the heading of the last chapter in this division of the book

The part of the book dealing with soil (pages 42 to 102) is an excellent and critical review of modern research in this field The personal experience of the authors enlivens the subject matter and the text is richly interspersed with schematic drawings, graphs, and tables A large color plate of 12 soil profiles (after Vilensky) is inserted. Another color plate depicts the morphological results of deficiency for N, P, and K upon oats (after Kruger and Wimmer) inserted in a 40-page chapter upon the interrelation of climate, soil, and plant Rotations are taken up from a biological as well as from an economic point of view

Especially important is a review of the prevalent methods for determining the "want" of soils for the main nutrients N, P, and K. Mitcherlich's, Neubauer's, and Niklas' biological methods; the chemical test after Lemmermann; and the Dirks method are described The application of fertilizers and the control of soil acidity are treated separately for the different constituents and special attention (and 2 color plates) are devoted to the weeds serving as "sign posts" for specific soil deficiencies. Also, the chapter on cultivation of the soil spells the prolonged research which the senior author has conducted in this field The chapter headings in this section are as follows: The Purpose of Cultivation, The Effect of Cultivation, Time of Cultivation, Cultivation Previous to Seeding, Special and Unusual Methods, Horse or Tractor, Cultivation of Light Soil, and Cultivation of Heavy Soil.

The three last divisions of the book deal with the care for the plant from the time of seeding (including seed treatments) until harvest and through storage

Careful attention is again given to the weed problem, a color plate and many text figures showing the young and adult weeds belonging to 15 species which may be eradicated with cyanamid. The book closes with an economic outlook. Germany's agricultural output suffices to feed her population. Science, after having led the way to this goal now must show how yields may be stabilized, how quality standards can be raised, and how costs of production can be reduced.

The book is printed in latin type and written in fluent easy language going straight to the point throughout. An alphabetical index renders the subject matter readily accessible. It is deplorable that a literature list (probably because it would have been excessively long) had to be omitted, since the volume exceeds the scope of an elementary text book. (B. R. N.)

AGRONOMIC AFFAIRS

QUIVIRA WHEAT

Through a typographical error in the manuscript, the spelling of the name of Quivira wheat (Kans. No. 2628, C. I. No. 8886) is incorrectly given as "Quivera" in the report on the registration of improved wheat varieties on pages 975 to 978 of the December, 1932, number of the JOURNAL.

NEWS ITEMS

AT THE annual business meeting of the Iowa Section, the following officers were elected for the ensuing year: *President*, Dr R H. Walker, Research Associate Professor of Soils; *Vice-President*, Dr A A. Bryan, Assistant Agronomist, Corn Investigations, U. S. Dept of Agriculture; and *Secretary-Treasurer*, Roy E. Bennett, Research Assistant Professor of Soils.

J L. BOATMAN, Extension Associate Professor of Soils at Iowa State College, has spent the past six months with the Bankers Life Insurance Company assisting them to develop a soil management program for their fore-closed farms.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 FEBRUARY, 1933 NO. 2

A NEW TYPE OF COTTON SORTER[1]

E. H. PRESSLEY[2]

While making selections of cotton in the field during the fall of 1931, the attention of the writer was called to the need of some machine that could be used in making fairly quick and accurate determinations of the amount of short fiber or "substaple" contained in the lint of the various plants studied.

Cook[3] makes the following statement: "That cottons of all varieties have substaple or under fiber can readily be seen by pulling out the long fibers from combed samples and leaving the short fibers attached to the seed."

When the amount of this short fiber is either noticeably small or large, selection or rejection of plants otherwise satisfactory can be made in the field. However, when large numbers of plants are to be studied, separation on this basis becomes difficult because differences in most cases are not great enough to be estimated with any degree of accuracy. It was felt that some means was needed whereby accurate determinations could be made and a numerical value given to each plant.

At first it was thought that possibly a Johansen sorter which was available might be used for this purpose. After several trials this machine was found to be unsuited to the work for numerous reasons. As the lint can be straightened by combing while it is still attached to the seed much more easily and quickly than by hand pulling after it is ginned, it was desirable to use unginned samples consisting of 10 seeds from each plant. The lint on these seeds was combed out straight, as shown in Fig. 3, and then placed on the Johansen sorter so that it could be pulled out into 1/16-inch classes. It was found that only about five seeds could be placed on the sorter at one time due to the short length of the combs. This size sample was not considered

[1]Contribution from the Department of Plant Breeding, University of Arizona, Tucson, Ariz. Received for publication May 31, 1932.

[2]Associate Plant Breeder. The writer wishes to acknowledge the valuable assistance given by Professor W. E. Bryan in taking all photographs from which plates were made and in the preparation of the text of this paper.

[3]COOK, O. F. Cotton improvement through type selection, with special reference to the Acala variety. U. S. D. A. Tech. Bul. 302. 1932.

representative. More than one sample of five seeds could be run over the machine, but this would increase the amount of time necessary and make the keeping of each class in its proper place more difficult. The greatest objection to the Johansen sorter, however, lies in the fact that the force necessary to pull the fibers through the closely spaced teeth of the combs in addition to the force necessary to detach the fibers from the seed is sufficient to cause some breakage.

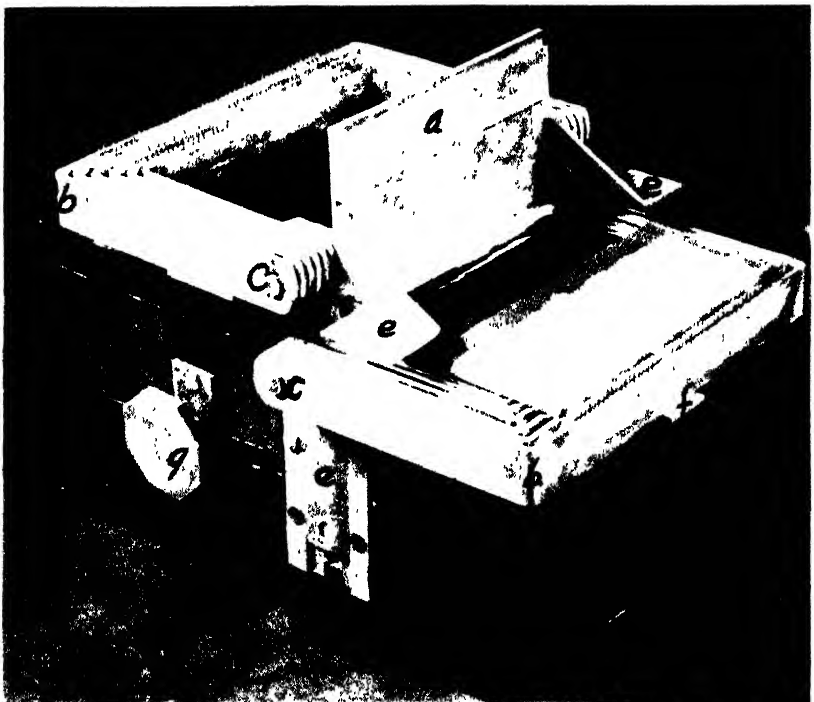

FIG. 1.—Sorter with sample of cotton in place. (a) Brass plate for holding seed in place; (b) right-angle bends in combs; (c) holes in end sections of combs; (e) parts of slides; (f) brass strip holding lower combs up in position; (g) end of rod to which f is attached by means of rack and gear.

This, of course, renders any results obtained in this manner valueless The amount of time necessary to gin and run a sample of cotton over the Johansen sorter in the usual way is so great as to make it unsuited for the work from the standpoint of time alone where a large number of plants is to be examined.

DESCRIPTION OF SORTER

Taking the above facts into consideration, the writer constructed a sorter which would eliminate, as far as possible, the objections encountered in the use of the Johansen sorter. Figs. 1 and 2 show some of the details of construction and use of this sorter. Fig. 1 shows the lower set of combs in position and a sample of 10 seed combed out and

in place. The upper set of combs is shown turned back out of the way. These are the positions that the two sets of combs must occupy while the sample is being placed in the machine. After the sample is so placed, the upper set of combs is brought over and let down upon the lower set with the sample in between. Fig. 2 shows the sample in this position. In Fig. 2, two of the lower combs have been dropped down

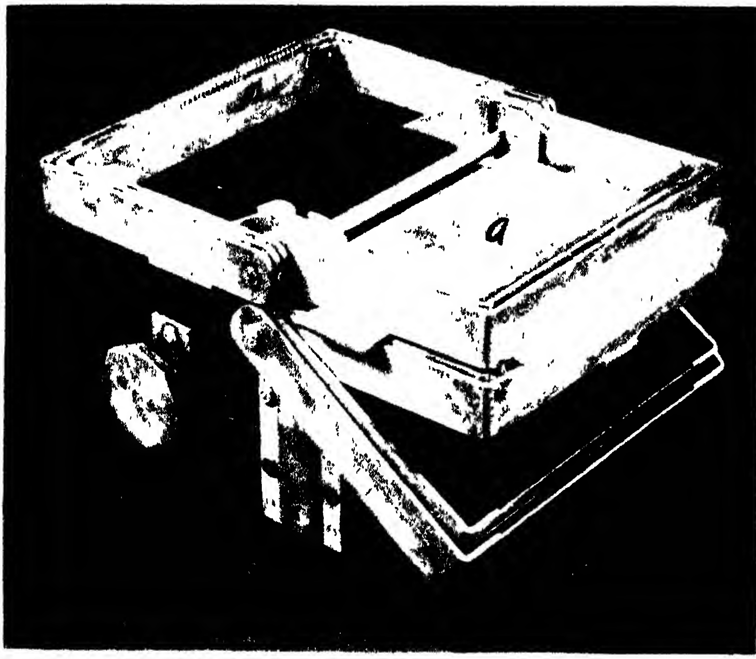

FIG. 2 -Same as Fig. 1, except that the positions of the combs have been changed. (a) Brass plate lowered upon seed.

out of the way while three of the upper ones have been raised and laid back so that the ends of the fibers may be reached. As the fibers are pulled out, additional combs may be lowered or raised until all of the lint is removed from that side of the seed. The seed are then removed, turned around and replaced in the machine, and the lint from the other side sorted in the same way. A fairly heavy brass plate, shown at "a" in Figs. 1 and 2, is hinged at one side so that it may be lowered upon the seed to hold them firmly in place while the lint is being sorted. Nippers, such as those furnished with the Baer and Johansen sorters, may be used to remove the lint from the seed.

Each set of combs consists of six individual combs. These were made out of 1/8 by 1 inch strip brass bent at right angles as shown at "b" in Fig. 1. The middle section of the first or inner comb of each set is 6 inches in length. The middle section of each succeeding comb of each set is 3/8 of an inch longer than the corresponding section of the preceding comb. Thus the middle section of the second comb of each set is 6 3/8 inches in length; that of the third, 6¾ inches; that of

the fourth, 71/8 inches, etc. When bent and placed together, there is sufficient space between the end sections to allow the combs to be lowered or raised easily. One-eighth inch spacers were placed between the middle sections of the combs of each set, these six combs clamped tightly together, and holes drilled in the end sections as shown at "c" in Fig. 1.

Common sewing needles, size No. 5, were then soldered to the outer surface of the middle section of each comb. These needles or teeth were placed 1/8 inch apart on all combs except the first comb of the lower set. Here they were placed 1/16 inch apart. This was done because the seed making up the sample are placed directly against the teeth of this comb, and all the force necessary to remove the lint from the seed is exerted against this set of teeth. More teeth could be used in all combs, but this is not considered necessary. As one end of each fiber is attached to the seed coat there is very little slipping, and the only function of the teeth other than those of the first lower comb is to hold the lint straight and in place while it is being pulled out. The teeth on this machine are ¼ inch long. However, it is believed that teeth from 3/8 to ½ inch in length should be used.

Rods through the holes in the end sections retain the combs in their proper relative positions and allow the individual combs to be raised or lowered when necessary. One of these rods can be plainly seen in Fig. 2. The rod holding the lower set of combs is firmly attached to the base and is therefore stationary. The one holding the upper set, however, is attached to a pair of slides which are shown at "e" in Fig. 1. These slides may be raised or lowered at will by means of a set of levers located inside the base. As the upper set of combs is attached to these slides it is also raised or lowered at the same time. This was done so that the upper set of combs, when brought over, may be lowered upon the sample of cotton in such a way as to allow the teeth to enter the sample without disturbing the arrangement of the fibers. In Fig. 1 the slides and upper set of combs are in the raised position, while in Fig. 2 they are lowered so that there is only 1/8 inch separating the two sets of combs. The lower combs are held up in position by the brass strip whose end is shown at "f" in Fig. 1. This strip extends horizontally underneath the combs and into the base where it is connected by means of a rack and gear to the rod shown at "g" in Fig. 1. The combs are lowered one at a time by turning the rod and moving the strip inward.

The rod holding the lower combs, and the two slides to which the rod holding the upper set is attached, are so fastened to the base that the teeth or combs of the two sets alternate when placed together. This makes the distance between the upper and lower combs when in position 1/8 inch.

By using thinner material and doubling the number of combs in each set, the space between combs can be reduced to 1/16 inch, and the cotton thus sorted into 1/16-inch classes. This, however, will double the amount of time necessary to make the weighings and calculations. The writer does not believe that the results obtained by making this finer classification justify the extra amount of time and labor involved. The size of the sample may be increased by making

the middle section of the combs longer. Between 0.5 and 0.6 inch of linear comb space is required for each seed in the sample. A 10-seed sample can be easily placed on 6 inch combs. A sample of 20 seeds would require combs approximately 12 inches in length.

PREPARATION OF SAMPLE FOR SORTING

In the work discussed below each sample sorted was made up of 10 seeds. One seed was taken from each of 10 different bolls that grew on different parts of the plant. In making up the samples every effort was made to have them as nearly comparable as possible.

The lint on the seed was carefully divided into two approximately equal parts. This was done by means of a dissecting needle, and every precaution was taken to minimize the removal of lint from the seed. The lint was then combed out straight, as shown in Fig. 3, and sorted into 1/8 inch classes.

During the sampling, dividing, and combing processes, a certain amount of lint is removed from the seed. This amount will vary in most cases from 12 to 25% of the total. In handling 232 samples in the laboratory the average amount lost in this way was 19.3%. This loss can be reduced to a minimum by holding the lint firmly between the thumb and forefinger as close to the seed as possible, and then combing out the tangled ends of the fibers first. After this is done the fibers close to the seed can be combed out without a very great loss. When the seed instead of the lint is held while the tangled ends are being combed out, a much greater loss may be expected.

Several samples of lint removed from the seed in this way were sorted on the Johansen sorter to determine the amounts of the various classes lost in preparation. It was found that the relative amount of each class removed did not differ materially from that remaining on the seed. In other words, the loss from the various classes was approximately proportional. Since this loss is approximately proportional and since the total amounts removed from the different samples do not vary to any great extent, it is felt that this lint can be discarded without any great error.

Of course ideal results could be obtained only if no lint were lost during the preparation of the sample for sorting. This is impossible, however. All samples to be compared should be handled in as nearly the same manner as possible. Where one person is doing all the work this should not be difficult. Where two or more persons are working on the same samples the activities of each should be confined to a particular set of operations. All samples should be made up by the same person to assure their being comparable. For the same reason the dividing of the lint on the seed of all samples should be done by one individual. The amount of lint removed from the seed during this operation depends to a great extent upon the care exercised. It is of still greater importance that all combing be done by one person as it is here that the greatest loss occurs. This loss may be as high as 50% of the total if the lint is not properly held while the combing is being done. When each operation is performed in the same manner for all samples compared, the error introduced should be negligible.

DISCUSSION OF RESULTS OBTAINED

In this discussion the 1/8-inch class containing the largest amount or percentage of lint is referred to as the "modal eighth." Likewise, the 1/4-inch class composed of the two largest 1/8-inch classes is referred to as the "modal quarter," while the 3/8-inch class composed of the three largest 1/8-inch classes is referred to as the "modal three-eighths." It is probable that the largest 1/8-inch class in many samples of cotton is not recovered intact on the sorter. Suppose, for example, that the greatest 1/8-inch class in a certain sample varies in length from 1 1/16 to 1 3/16 inches. When placed upon the sorter, this class will be divided by the 1 1/8-inch comb so that when it is sorted a part of it will be removed in the class varying in length from 1 to 1 1/8 inches while the remainder will be removed in the class varying in length from 1 1/8 to 1 1/4 inches. This result can be avoided by placing the fibers on velvet pads and measuring each "pull" separately. This greatly increases the amount of time necessary, and can not be done when time is limited and the number of samples large. For the reason stated above the modal quarter is considered of more importance and is more apt to represent the comparative value of the sample than is the modal eighth.

In 1931, more than 600 plants were harvested and brought into the laboratory for lint studies. The vegetative characters of each plant were carefully observed in the field. The lint was also examined, and only those plants considered worthy of more careful examination were harvested. Twenty-seed samples of each plant were combed. Approximately two-thirds of these 600 plants were discarded because of the obvious lack of uniformity of the lint. The lint of the remaining 232 plants appeared fairly uniform from a careful study of the combed samples. The following table shows the range of variation found when 10-seed samples of these plants were sorted.

TABLE 1.—*Range of variation in percentage of lint between highest and lowest classes in 232 plants sorted.*

Percentage of lint	Modal 1/8	Modal 1/4	Modal 3/8
Highest	40.0	69.5	79.0
Lowest	24.2	46.3	61.2
Difference	15.8	23.2	17.8

As can be seen in Table 1 there was a difference of 15.8% between the plants with the highest and lowest modal eighths. In the modal quarter there was a still greater difference of 23.2%. In the modal three-eighths the difference was 17.8%. The fact should be borne in mind that a careful study had already been made of these plants, and that they had been retained because of the uniformity of the lint as shown by the combed 20-seed samples. If the 400 discarded plants had also been sorted, there is every reason to believe that a much greater range of variation in each class would have been found.

As the 232 plants selected were approximately equally divided among several well-known varieties, it was thought worth while to see if any varietal difference could be detected. The average amount

of lint in each class for the plants of each variety was determined. The results are shown in Table 2.

TABLE 2.—*Average percentages of lint in the three classes for six varieties from which selections were made.*

Variety No.	Lint in modal 1/8, %	Lint in modal 1/4, %	Lint in modal 3/8, %
1	32.0	58.7	75.1
2	32.1	58.1	73.1
3	30.8	57.9	72.1
4	31.2	55.7	73.2
5	30.1	54.7	70.8
6	29.5	54.5	70.6
Difference between Nos. 1 and 6	2.5	4.2	4.5

In Table 2 the varieties are arranged in the order of the amount of lint in the modal quarter. As would be expected the range of variation is not nearly so great as is the range between individual plants. There was a considerable difference, however, between the highest and lowest varieties. The names of varieties are purposely omitted.

In order to emphasize the difficulty of recognizing and estimating the amount of waste or substaple from the general appearance of a combed sample of cotton, a more detailed discussion of two plants will be given

Combed samples consisting of 20 seeds from each of these plants are shown in Fig 3. These samples were taken in the following manner. At the time of harvesting, 20 locks, consisting of 1 lock from each of 20 different bolls that grew on different parts of the plant, were picked separately for use in the laboratory. In making up the samples shown in the illustration, one seed was taken from each of the 20 locks These seed were so taken that all parts of the lock were represented in the sample. This was done because of the fact that there is considerable variation in the degree of butterfly, or shortening of the lint on the base of the seed, shown by seed coming from different positions in the lock In the plants studied by the writer this butterfly condition was most pronounced in the pair of seeds at the base of the lock and less pronounced in each succeeding pair.

As is clearly shown by the samples in Fig. 3, plant No. 1 appears much more uniform in every respect than does plant No. 2. The length of lint of plant No 1 appears to be very nearly the same on all seeds, while that of plant No. 2 shows the butterfly condition to a high degree. Measurement of the degree of butterfly of these two samples showed an average of 6.7 degrees for No. 1, and 22.3 degrees for No. 2. By degree of butterfly is meant the average number of degrees in the two angles formed by a line running lengthwise through the center of the seed and two other lines running parallel to the ends of the fibers. This is clearly illustrated by Fig. 4.

After the samples shown in Fig. 3 were photographed they were sorted with the results shown in Table 3.

TABLE 3.—*A comparison between plants Nos. 1 and 2 of the percentages of lint in the modal one-eighth, one-quarter, and three-eighths classes.*

Sample No.	Lint in modal 1/8, %	Lint in modal 1/4, %	Lint in modal 3/8, %
1	29.4	49.1	66.8
2	28.7	54.7	71.9
Difference	0.7	5.6	5.1

The percentages of lint in the modal eighths of the two plants were practically the same, there being a difference of only 0.7%. However, there was a difference of 5.6% between the two modal quarters and of

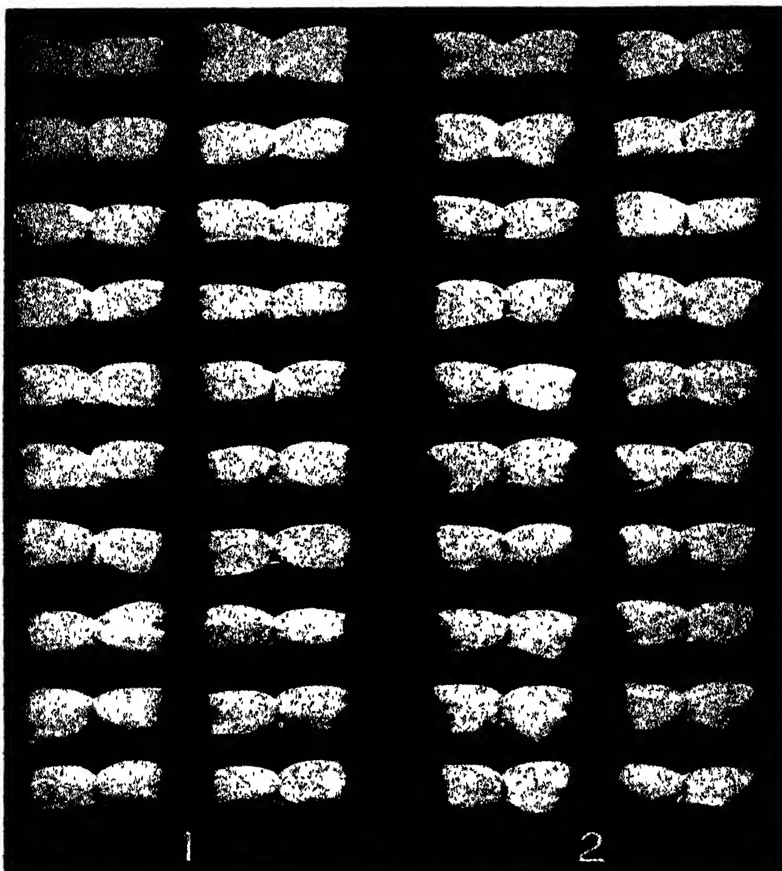

FIG. 3.—Twenty-seed samples of plants No. 1 and 2 combed out. Note the high degree of butterfly in No. 2.

5.1% between the two modal three-eights. In the last two instances the differences were in favor of plant No. 2 regardless of the fact that plant No. 1 appears much more uniform. The amount of sub-

staple in sample No. 1 was large enough to more than balance the extreme butterfly condition found in many of the seed of No. 2. This substaple is so intermingled with the longer fibers that it cannot be observed until the longer fibers have been removed from the seed.

The writer does not mean to imply in the above discussion that plants showing the butterfly condition are desirable, but to point out the difficulty of estimating the amount of substaple in a sample of cotton whose general appearance is otherwise satisfactory. It is manifestly impossible to find a highly uniform lint where butterfly exists to a very great degree. This is also true where there is a large amount of substaple present. Cook[4] states that, "Butterfly cotton is undesirable on account of the irregular staple length, and variations showing this tendency should always be rejected. . . . The tendency to butterfly variations is very general, though much more pronounced in some varieties and lines of descent than in others."

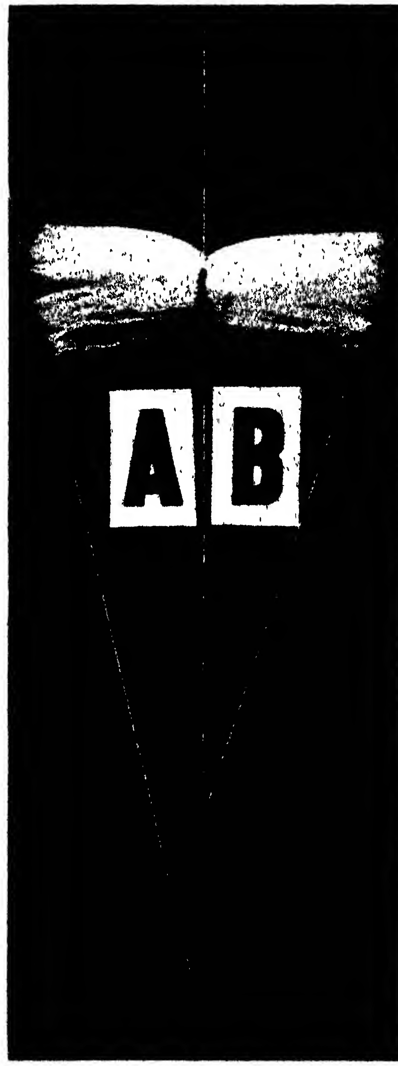

FIG. 4.—An illustration of what is meant by the term "degree of butterfly." The degree of butterfly is the average number of degrees in the two angles A and B. A device for quickly and accurately measuring and averaging these angles has been constructed and will be more fully discussed in the near future.

SUMMARY

A new type of sorter upon which combed samples of unginned cotton may be sorted is discussed.

The only method by which the amount of sub-staple or waste in a sample of cotton can be accurately determined is by sorting. Lint of plants or varieties otherwise similar in appearance can be compared in this manner, and a numerical expression of the uniformity of each assigned.

Much time and effort may be saved by the use of a sorter upon which the combed seed can be placed and the lint sorted into the

[4] *Loc. cit.*

various classes. A further saving may be made by removing four or five of the largest classes separately, and then removing the remainder of the lint in one class. This will give the percentages of usable fibers in the longer classes, and will eliminate several operations in pulling, weighing, and calculating.

As large a sample as is desirable may be sorted either by repeating the process or by making longer combs on the sorter, thus allowing more seed to be used in each sample. From 0.5 to 0.6 inch linear comb space is required for each seed.

The uniformity of the length of lint of a sample cannot always be estimated from the combed seed. A sample fairly uniform in appearance may in reality contain a higher percentage of short fibers than another showing the butterfly condition to a much greater degree

Where environmental conditions are approximately the same for all plants compared, those showing the greatest lack of uniformity and the greatest amount of waste fiber should be discarded.

VARIATION OF YIELDS OBTAINED IN SMALL ARTIFICIALLY CONSTRUCTED FIELD PLATS[1]

R. J. Garber and W. H. Pierre[2]

Small "artificial" plats have long been used in soil fertility investigations although it has been only in recent years that considerable interest in them has developed in the United States. This greater interest in the use of artificial plats is partly a result of the introduction of a new type of "soil frame" by Lyon and Leland (4)[3] of the Cornell Agricultural Experiment Station. These investigators believe that artificial plats or frames are more satisfactory than ordinary field plats, since their use results in a reduction of variations in soil productivity among plats. Little information is available, however, regarding the variability in yields on such "artificial plats." It is the the purpose of this paper to present additional data on this subject

CONCRETE FRAMES

In the late summer and early fall of 1928, 30 concrete frames were constructed on the agronomy farm of the West Virginia Agricultural Experiment Station, very similar to the largest frames described by Lyon and Leland (4) at Cornell University. The walls were made 24 inches high and 6 inches in thickness. The inside dimensions of each frame were 9 feet 4 inches by 4 feet 8 inches, thus giving an area of 0.001 of an acre. The surface of the frames was made horizontal and raised or lowered by steps, depending on the contour of the ground.

[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 113. Received for publication June 7, 1932.

[2]Head of Department and Associate Agronomist, respectively.

[3]Reference by number is to "Literature Cited," p. 105.

The frames were arranged side by side (not end to end) in a single series. A 4-inch drain tile was laid below and to the outside of the end walls.

Previous to constructing the concrete frames, surface soil to a depth of 8 inches was removed and placed to one side and then subsurface soil, also to a depth of 8 inches, was removed and placed on the other side. In filling the frames the order was reversed. A wheel-barrow was filled with sub-surface soil and this was distributed approximately equally among the 30 frames by placing a small shovelfull of soil in each. After the desired amount of sub-surface soil had been placed into the bins and leveled off, the same procedure was followed with the surface soil

In the spring of 1929 Wilson soybeans were planted in the 30 plats to study uniformity of yields Two rows approximately 28 inches apart were seeded lengthwise (east and west) in each plat and the seeds were spaced about 1 inch apart along the rows No soil treatment other than fitting the seedbed was given to any of the plats. When the soybeans were considered sufficiently mature for hay they were cut, dried in a heated room, and the yield in grams of dry hay per row (about 1% moisture) was determined.

In the early fall of 1929 the plats were seeded to a uniformity crop of Reliable 80 winter wheat Four rows of wheat approximately a foot apart were seeded lengthwise in the plats, thus leaving about 10 inches between each outside row and the side concrete wall. Yields of seed and dry straw were determined separately for each row.

The following spring, in connection with a phosphorus fertilization study, 15 different soil treatments in duplicate were given to the 30 plats just before seeding a crop of Sudan grass. The Sudan grass was grown in rows similar to those of wheat. Yields were determined of dry Sudan grass hay per plat.

The yields per row and per plat for soybeans and for wheat are shown in Tables 1 and 2, respectively.

TABLE 1.—*Soybean yields obtained in "soil bins" at the West Virginia Experiment Station agronomy farm in 1929.*

Dry weight in grams			Dry weight in grams		
Plat No.	Row a	Row b	Plat No.	Row a	Row b
1	865	898	16	850	885
2	925	879	17	843	892
3	735	845	18	815	870
4	765	818	19	791	860
5	785	790	20	855	878
6	863	853	21	835	900
7	865	928	22	810	888
8	785	923	23	915	881
9	865	968	24	815	853
10	922	915	25	895	865
11	852	918	26	848	875
12	824	912	27	841	801
13	871	876	28	842	863
14	955	1011	29	829	825
15	854	896	30	745	815

TABLE 2.—*Wheat yields obtained in "soil bins" at the West Virginia Experiment Station agronomy farm in 1930.*

Plat No.	Air-dry weight in grams of: Straw and grain				Grain			
	Row a	Row b	Row c	Row d	Row a	Row b	Row c	Row d
1	650	469	452	603	237	169	160	227
2	615	504	480	569	220	185	173	206
3	661	513	548	702	255	190	205	268
4	680	495	533	712	240	170	179	250
5	767	527	460	623	280	193	165	214
6	684	515	517	629	220	168	170	212
7	633	536	483	621	225	183	156	220
8	640	473	488	606	227	170	170	214
9	611	550	473	628	212	197	165	225
10	652	515	490	660	250	214	205	250
11	705	596	554	642	244	182	173	230
12	607	506	480	596	212	180	170	210
13	603	555	489	569	210	194	170	200
14	552	474	496	542	185	140	154	165
15	566	507	460	551	190	170	158	194
16	565	460	470	525	194	156	156	170
17	523	451	451	542	180	155	153	195
18	565	465	500	538	205	166	176	192
19	540	448	494	520	183	155	162	180
20	542	480	557	532	204	180	206	195
21	555	470	491	549	195	165	175	205
22	564	492	487	660	195	173	175	230
23	561	485	470	638	220	170	169	240
24	585	516	511	647	235	195	193	250
25	597	482	510	550	227	185	200	214
26	545	424	387	605	190	140	128	215
27	563	449	484	575	210	158	170	201
28	582	503	562	615	206	185	204	230
29	565	506	526	559	195	175	185	202
30	605	507	505	515	210	175	182	183

The variation in the yields of soybean hay per row may be analyzed into that due to variation within the plats and that due to variation between them. For this purpose Fisher's (1) method of analyzing variance is effective. In Table 3 are shown the results of such analysis.

TABLE 3.—*Analysis of variance in yields of soybean rows.*

Variance	Degree of freedom	Sum of squares	Mean square	σ	$\log_e \sigma$	Diff. Z
Between plats	29	109,382.926	3,771.8250	61.4152	4.1176	0.3966
Within plats	30	51,185.5	1,706.1833	41.3060	3.7210	
	5% point = 0.3062; 1% point = 0.4366					

The variation between plats is somewhat greater than that within plats, but the difference is barely significant, the Z value being between the 1 and 5% points in Fisher's tables.

An examination of the wheat yields showed marked evidence of "border effect," as may be seen from the data in Table 2. The grain yields of rows a and d, the border rows, average greater than the yields of rows b and c. For this reason the center rows only (b and c) of each plat were used in making the analysis of variance. It may be seen from Table 4 that the variance between plats is significantly greater than that within plats, the Z value being 0.7879. The wheat yields indicate that, although the soil in all the plats had been mixed, there was still more variation among plats than is desirable.

TABLE 4.—*Analysis of variance in yields of central wheat rows.*

Variance	Degree of freedom	Sum of squares	Mean squares	σ	$\text{Log}_e\ \sigma$	Diff. Z
Between plats......	29	14,517.782	500.6132	23.372	3.1078	0.7879
Within plats.......	30	3,105.500	103.5167	10.1743	2.3199	
	1% point = 0.4366					

Another method of studying the variation in yields among plats is by correlation analysis. The linear correlation coefficients shown in Table 5 were calculated in the usual manner. The correlation coefficient between the weights of soybean hay produced in row a and row b of the same plats was found to be 0.569, a significant value according to Fisher's Table 5, A. Likewise, a significant correlation coefficient (0.651) was obtained between the weight of wheat grain in center rows b and c of the same plats.

TABLE 5.—*Correlation coefficients of yields obtained in "soil bins."*

Correlation between	n	r
Weight of soybean hay in row a and in row b of same plats.........	30	0.569
Weight of wheat grain in center row b and in center row c of same plats	30	0.651
Weight of soybean hay per plat and weight of wheat (grain+straw) per plat..	30	—0.186
Average weight of soybean hay per row per plat and average weight of wheat (grain+straw) per row per plat for the two central rows	30	—0.079
Weight of soybean hay per plat and weight of wheat grain per plat..	30	—0.216
The differences among yields of duplicate plats of Sudan hay and among the same plats (center rows only) of wheat (grain+straw)	15	0.054
The differences among yields of duplicate plats of Sudan hay and among the same plats (center rows only) of wheat grain.	15	0.293
The differences among yields of duplicate plats of Sudan hay and among the same plats of soybean hay........................	15	—0.369

$n = 13,\quad P = 0.1,\quad r = 0.4409$

$n = 28,\ \begin{cases} P = 0.1, & r = 0.3069 \\ P = 0.01, & r = 0.4640 \end{cases}$

This means that approximately 42% of the total variance in yield of wheat grain of one central row was associated with that of the other central row in the same plat, whereas approximately 32% of the total variance in yield of soybean hay of one row was associated with that of the other row in the same plat.

The same general conclusion can be obtained from the data in Tables 3 and 4. It will be noted that of the total variation (sum of squares) in the yields of the individual rows 68% is due to differences between rows of different plats in the case of soybeans and 82% in the case of wheat. These results, particularly in the case of wheat, show that there is a greater variation from plat to plat than one might expect in view of the precaution taken to mix the soil thoroughly.

A measure of the permanency of differences between plats may be obtained by calculating the correlation coefficients between yields of soybeans and of wheat. Such coefficients are also shown in Table 5. The weight of soybean hay per plat and the weight of wheat (grain + straw) per plat showed a correlation of —0.186; the average weight of soybean hay per row per plat and the average weight of wheat (grain + straw) per row per plat for the two central rows showed a correlation of —0.079; and finally, the weight of soybean hay per plat and the weight of wheat grain per plat showed a correlation of —0.216. None of these coefficients is significant. There is no evidence, therefore, that the differences between plats as revealed by the soybean hay yields in 1929 are associated with the differences revealed by wheat yields in 1930.

It has been pointed out that fertilizer treatments in duplicate were applied to the 30 plats in the spring of 1931, just prior to seeding Sudan grass The relations were determined of the differences between the yields of dry Sudan hay of duplicate plats to the differences between yields of soybeans and also of wheat of the same duplicate plats. No significant correlation was found (Table 5), thus showing that the differences revealed by the uniformity crops did not persist.

Inasmuch as persistence of soil heterogeneity has been demonstrated for ordinary field plats (2, 3), it is interesting to note that the inter-annual correlation coefficients among yields obtained in these soil bins did not show such a relationship. Of the six coefficients, the greatest (—0.369) was obtained between the differences among yields of duplicate plats of Sudan hay and the differences in yields among the same plats of soybean hay. This coefficient, however, is not significant. Where $n = 13$, a coefficient of the magnitude 0.4409 would be required even for a probability of little significance ($P = 0.1$).

In view of the results obtained from an analysis of variance between rows it may seem contradictory to find no persistence of differences in yield between the different plats. This might be explained on the basis either that the variability is due to causes other than that of soil heterogeneity or that soil differences still remain between the plats but that they affect the growth of these three crops differently. If soil heterogeneity is still a factor causing differences in yield, it is probable that physical soil differences (possibly in the subsoil which has not been disturbed) are having a greater influence than chemical differences. This would seem to be indicated by the fact that wheat yields showed a greater variance between plats than did soybean yields. Wheat is a winter crop, and differences in drainage between the different plats in the late fall or early spring might account partly

for differences in yield. Soybeans and Sudan grass, on the other hand, are short-season summer crops.

It remains to compare the variability of the yields of these plats with the yields of the smaller plats reported by Lyon and Leland (4). In the study at Cornell, 56 soil frames of 0.0001 acre each were uniformly cropped with fodder corn, barley, and millet during 3 successive years. Four different soil types were represented, thus making 14 soil frames available for each type. The probable errors of single determiniations expressed in percentages of means for total yield per plat during the 3-year period were as follows: Ontario loam, 3.89; Volusia silt loam, 3.38; Wooster silt loam, 4.36; and Canfield silt loam, 3.00. The similarly calculated probable error of the total yield (wheat, grain + straw, and soybean hay) per plat for the 2-year period in the experiment reported here was found to be 2.5. Since this value would probably have been even smaller if uniformity yields of 3 years had been averaged, it is indicated that the use of plats of 0.001 acre instead of 0.0001 acre in area results in considerably less variation in yield.

Probable errors based on total yields per plat over a period of years, however, do not indicate the magnitude of the variation in any one year The probable error of a single determination expressed as a percentage of the mean yield per plat for soybeans was found to be 3.4, and the similarly calculated probable error based on the yield per plat of total wheat grain was found to be 6.2. A probable error of 6.2 was also obtained when calculations were based on total wheat yield per plat of grain plus straw.

SEWER TILE FOR ARTIFICIAL PLATS

In the fall of 1929, after making suitable excavations, 42 24-inch glazed sewer tile were placed in the ground (bell downward) on the agronomy farm of the West Virginia Experiment Station in such a manner that approximately 2 inches of the tile extended above the surface. The 4-inch drain was laid from 2 to 3 inches below and in the center of each tile. A thin layer of river gravel was placed immediately over the drain and this was followed with a layer of subsoil. The next spring the sewer tiles were filled with thoroughly mixed comparable soil, but soil that had been treated differentially with respect to lime and fertilizer. In filling the tiles equal quantities by weight of the soil were placed in position, and precautions taken to obtain uniform firming. In spite of these precautions considerable variability was observed among the filled tile in depth from top of tile to surface of soil within. This variation was due partly to the slight variation in the diameters of the tile.

Grimm alfalfa was seeded soon after the tiles had been filled and late in the summer a crop of hay was harvested. The yield in grams of dry hay produced in each tile was determined. Inasmuch as the soil treatments had been made in triplicate it was possible to study the relation of yields to variation (range ¼ to 2¼ inches) in average depth (three measurements for depth in each tile just before alfalfa was harvested) from top of tile to surface soil within. This was done by expressing deviations in yield as a percentage of the average for

triplicate plats and likewise deviation in depth as a percentage of the average for the same triplicate plats. The correlation coefficient between the two sets of percentage deviations was found to be 0.668, indicating a significant and rather marked relationship. Stated in another way, approximately 45% of the total variation in alfalfa yields obtained from the first cutting was associated with variation in depth from top of tile to surface of soil within.

During the season of 1931 three cuttings of alfalfa were removed from the tile. In a manner similar to that used the previous year the correlation between the total yields in 1931 and the depth measurements made in 1930 was found to be 0.085. Apparently the differential effect on yield of average depth from top of tile to surface of soil within, was largely obliterated during the second season. The differences in average depth of soil in the different tiles in 1931, however, were considerably less than in 1930.

These results indicate that in using small receptacles, like tiles or cylinders, care should be taken to have containers of equal diameter and to have the soil come to the same depth in each cylinder. In using metal cans in which the bottom has been removed, as containers it has been observed that freezing and thawing tends to raise the cylinders out of the ground. It is evident that some precaution should be taken against this occurrence. By using glazed sewer tiles and placing the bell downward, no difficulty will be found from an upward movement of the tile.

As previously mentioned, three cuttings of alfalfa were removed from the tiles in 1931. The probable error[4] of the total yield of alfalfa from each tile expressed as a percentage of the means was calculated. In making this calculation it seemed advisable to eliminate two treatments from consideration since one plat in each was found to give very abnormal yields. On the basis of the remaining 36 plats the probable error of a single determination expressed as a percentage of the mean was found to be 6.74. This indicates that with such crops as alfalfa, at least, small frames may give satisfactory results.

SUMMARY AND CONCLUSIONS

A study of the variation of yields of wheat, soybean hay, and Sudan hay obtained during 3 years from 30 concrete "soil bins" of 0.001 acre each indicated that the soil heterogeneity, in so far as it influences yield over a period of years, may largely be removed by thoroughly mixing the soil. On the other hand, the uniformity crops of wheat and soybean hay show that the variance between plats in any one year is still too high to make replication unnecessary. The probable error of a single determination in percentage of the mean for the yield of soybean hay per plat was 3.4 and for the yield of wheat grain plus straw (also for grain alone) per plat was 6.2, whereas the probable error of a single determination in percentage for the total yield of soybeans and wheat (grain + straw) per plat was only 2.5%.

[4]The formula used $E_s = 0.6745 \sqrt{\frac{\Sigma\,(d^2)n}{N\,(n-1)}}$, where n = number of replicates of each treatment and N = total number of deviations.

This greatly reduced probable error for the 2-year period is partly explained by the lack of correlation between the yields of soybeans and of wheat.

A study of the variation of yields of alfalfa obtained from 42 soil bins made with 24-inch sewer tile shows that the height to which soil is filled in the tile may have a marked influence on the first yields of alfalfa. The correlation coefficient computed to measure this relation was found to be 0.668. The later yields of alfalfa apparently were not affected. The probable error of a single determination expressed as a percentage of the mean of total yields of alfalfa grown during 1 year in triplicated tile plats was found to be 6.74.

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THE COMPOSITION OF THE SPRING GROWTH OF SWEET CLOVER AS INFLUENCED BY PREVIOUS FALL TREATMENT[1]

C. J. BADGER and H. J. SNIDER[2]

The composition of the spring growth of sweet clover as influenced by previous fall treatment is of practical significance from the fertility standpoint, for it is important to know whether the fall growth may be removed without reducing the fertilizing value of the green manure. The removal of the fall growth may in a measure be compared to pasturing the sweet clover during the autumn months. The following investigation was undertaken with a view to determining, insofar as possible, the influence of the removal of a fall hay crop upon the composition of the following spring growth of sweet clover (*Melilotus alba*). For a comparative study of composition, determinations were made of the dry matter, nitrogen, phosphorus, and potassium. Samples for analysis were collected about the time the sweet clover is usually plowed down as a green manure for the corn crop.

Coe (1)[3] pointed out that fall clipping of sweet clover had a marked effect on the growth of the plants the following spring. Willard (3, 4) states that the leaves of sweet clover are food factories, and when destroyed before October 1, the supply of food material to be translocated to the roots is reduced. Whiting (2) and a number of

[1]Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of Illinois Agricultural Experiment Station. Received for publication June 18, 1932.

[2]Associate and Assistant Chief, Soil Experiment Fields, respectively.

[3]Reference by number is to "Literature Cited," p. 108.

others have shown the possibilities of sweet clover in supplying available nitrogen to the soil if properly handled.

The sweet clover used in this study was grown on the Enfield experiment field which is located on Yellow Gray Silt Loam on Medium Compact Plastic Clay (Bluford silt loam). Limestone had been applied several years previous to the seeding of the sweet clover so that the surface soil had a pH 7.20, while the underlying stratum of 7 to 20 inches had a pH 6.60. Manure, rock phosphate, and kainit had also been previously applied.

The sweet clover was seeded in the late winter (February 27) without a nurse crop. The crop was allowed to grow undisturbed until September 18, 1929, when a section of the plot was clipped and the growth removed for hay. On October 18, another section was cut and the hay removed and on still a third section the fall growth was allowed to stand undisturbed. The hay removed from each section amounted to approximately 1.4 tons of air-dry material per acre.

In the following spring, on April 25, 1930, samples of both roots and tops were collected from the three sections described above. The samples were collected from areas of 4 square feet in size with four of these squares harvested from each section. The results reported in Tables 1 and 2 were determined in each case from the average of these four squares, with the probable error of the mean calculated from the four variants.

The results shown in Table 1 indicate that the fall treatment of the sweet clover had a decided influence upon the number of plants growing the following spring and also affected the vigor of the top growth. The most favorable results were obtained where the fall growth was undisturbed. Under this treatment the number of plants was substantially larger and the top growth was fully twice as great as on the other two treatments. The October 18 removal had a slight advantage in number of plants and height of top growth as compared with September 18. The fall removal apparently did not greatly affect the root growth either in length or pounds per acre.

TABLE 1.—*Effect of different fall treatments of sweet clover on stand and top and root growth as of April 25, 1930.*

Fall treatment, 1929	No. plants 4 sq. feet	Tops, inches	Roots, inches
Hay removed Sept. 18	15 ± 1.5	5 ± 0.001	6 ± 0.002
Hay removed Oct. 18	17 ± 2.1	6 ± 0.2	6 ± 0.01
Growth undisturbed	29 ± 6.1	12 ± 0.03	6 ± 0.001

The data in Table 2 indicate that the removal of a fall hay crop from sweet clover very materially reduced the fertility value of the growth used as a green manure crop the following spring. The pounds per acre of dry matter, nitrogen, phosphorus, and potassium found in the spring growth from which no fall hay crop was removed were far greater than the amounts found in the growth from which the hay crop was removed September 18. There was only a slight gain in total dry matter, nitrogen, phosphorus, and possibly potassium in favor of the October 18 removal as compared with the September 18 removal.

TABLE 2.—*Effect of different fall treatments of sweet colver on dry matter, nitrogen, phosphorus, and potassium in the spring growth as of April 25, 1930.*

Fall treatment, 1929		Dry matter, lbs. per acre	Nitrogen		Phosphorus		Potassium	
			%	Lbs. per acre	%	Lbs. per acre	%	Lbs. per acre
Hay removed Sept. 18	Tops	735± 79	3.80	28.0	0.380	2.79	1.446	10.6
	Roots	665± 85	2.13	14.0	0.262	1.74	0.443	2.9
	Total	1,400±116	—	42.0	—	4.53	—	13.5
Hay removed Oct. 18	Tops	1,080±183	3.51	37.8	0.387	4.17	1.205	13.0
	Roots	510± 50	1.92	9.7	0.237	1.20	0.143	.7
	Total	1,590±191	—	47.5	—	5.37	—	13.7
Growth undisturbed	Tops	1,830±182	3.67	67.0	0.375	6.86	1.825	33.4
	Roots	630±101	2.19	13.7	0.262	1.64	0.252	1.6
	Total	2,460±257	—	80.7	—	8.50	—	35.0

Great variation in dry matter for the different fall treatments appeared in the top growth while the dry matter in the roots was fairly constant. The percentages of nitrogen and phosphorus found in the roots and tops respectively were fairly constant for the different treatments. The percentages of potassium found in the roots and tops respectively showed considerable differences. The highest percentage of potassium was found in the tops when the fall growth was undisturbed. The largest total pounds of nitrogen, phosphorus, and potassium were found in every case where the fall growth was undisturbed, and the differences due to this treatment as compared with the other two were sufficiently large to be significant.

From the fertility standpoint there can be no question but that the 80.7 pounds of nitrogen per acre where the fall growth was undisturbed, as shown in Table 2, is more valuable than the 42 pounds where the hay was removed September 18 or the 47 pounds where the hay was removed October 18. The conclusion may be drawn that the fall growth of sweet clover should not be removed on soils of this general character which are relatively low in nitrogen and organic matter. In actual farm practice, the advantage of removing the fall hay crop will depend on whether or not the 1.4 tons of fall hay is of more value than the extra organic matter and nitrogen added to the soil, together with the greater amount of phosphorus and potassium rendered available in not removing the fall growth of sweet clover.

In this work no account was taken of the fall growth of sweet clover which was not removed but remained on the land.

SUMMARY

This study was carried out in order to determine the influence of the practice of removing a fall hay crop upon the composition of the sweet clover the following spring at about the stage of growth that it is usually plowed under as a green manure. The effect of cutting on September 18 as well as on October 18 was compared to that where no hay was removed.

Analysis of the sweet clover tops and roots show that removal of the fall growth reduced the total dry matter, total nitrogen, phosphorus, and potassium in the following spring growth.

The results show also that cutting for fall hay reduces the vitality or winter resistance of the sweet clover plants. This was reflected in a thinner stand and a less vigorous spring growth where fall cutting was practiced.

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NAVARRO OATS[1]

T. R. STANTON[2]

During the last few years inquiries have been received from agronomists, plant breeders, and others interested in oat improvement relative to the origin and characteristics of Navarro oats. The variety is attracting interest because of its high resistance to the smuts of oats. Stanton, Coffman, and Tapke[3] have discussed briefly its probable value as breeding material for the development of smut-resistant varieties. In order that the variety may be most useful for this purpose information should be made available on its origin, description, classification, and productiveness. Navarro being a distinct new variety, its characters should be recorded.

ORIGIN

The variety was first brought to the attention of the writer a little over a decade ago by A. M. Ferguson, of the Ferguson Seed Farms, Sherman, Tex., under the name of "Three Grain Mesh" oat. At that time the following statement[4] regarding the variety was obtained:

"This is a distinct variety different from anything that we have ever encountered and its origin is unknown to us. It came to us from a farmer who reported that it had occurred as a 'stray' plant in his oat field."

About 3 years ago an effort was made to obtain additional information on the origin of the variety. In further correspondence,[5] Mr. Ferguson wrote as follows:

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication June 22, 1932.

[2]Senior Agronomist in Charge of Oat Investigations.

[3]STANTON, T. R., COFFMAN, F. A., and TAPKE, V. F. Oats that resist smut grown by experimentation. U. S. D. A. Yearbook, 1928: 481–482, 1929. (Separate No. 1077.)

[4]From letter of A. M. Ferguson, Sherman, Tex., dated May 23, 1921.

[5]From letter of A. M. Ferguson, Sherman, Tex., dated July 4, 1929.

"About 1919, the Rev. J. W. Hornbeak of Navarro County called my attention to a strain of oats that was grown by a farmer in his community. I obtained samples of this, and endeavored to secure something of its earlier history but could not get very much. But in this material was found what we first distinguished as 'Three Grain Mesh' oats, referring to the rather constant character of three grains to the spikelet. This name was used in our private records. Later on, we offered it for sale as a novelty, but not with a recommendation as to any specific value under the name of Ferguson Navarro oats, the word Navarro referring to Navarro County, Texas.

"We continued to propagate this oat and 'project' with it through a number of years. Its susceptibility to rust and a lack of drouth-resisting abilities indicated that it was quite inferior to other strains of red oats It was outstanding and attractive in appearance. It would produce to a rather high degree the three-grain character of the spikelet and had a rather attractive, round, plump grain. Its yielding qualities in our tests were not sufficiently promising for us to recommend it to a great extent. We have distributed samples widely to other experiment stations, but only in a few instances have favorable reports come to us Professor Ayres, of the Stoneville (Miss.) Experiment Station, who formerly assisted us in our plant-breeding work here, reported a few years ago that it stood at the top of the list for yield in one season at his station."

At the suggestion of the writer, Mr. Ferguson attempted to get further information from the Reverend Hornbeak but the latter had died, and no additional information was secured.

The fact that certain plant characters of the Navarro oat are more or less intermediate between those of varieties of *Avena byzantina* and *A. sativa* suggests a hybrid origin. It may have originated from a natural cross between Red Rustproof (Red Texas) and some variety of common oats. No variety of exact identical type has been received by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture from any foreign country. A variety received by this Division from the Bureau of Applied Botany, of Genetics, and Plant Breeding, Leningrad, U.S.S.R., in 1924 under the name of *Avena sativa* L. (*A. diffusa* Ash. and Gr., var. *segatalis*) (C. I. No.[6] 2137, F.P.I. No.[7] 60769) somewhat resembles Navarro in certain spikelet characters. Navarro may have originated in Russia and may have been introduced directly into the United States or by way of Mexico.

DESCRIPTION

Juvenile growth semierect to erect; plant early, very glaucous. Culms midlarge, stiff, slightly hairy at nodes, purplish-red at maturity; 60–90 cm tall. Sheaths deep green, glabrous or slightly hairy; culm leaves midwide, margins glabrous or slightly ciliate. Peduncle midlarge, straight, usually well exserted. Panicle equilateral, erect,

[6]C. I. No. refers to accession number of the Division of Cereal Crops and Diseases.

[7]F.P.I. No. refers to accession number of the Division of Foreign Plant Introduction.

short, narrow ovate, rachis nodes 4–7; branches short, ascending, scabrous, spikelets few, usually 3-flowered, occasionally 4-flowered; florets plump. Glumes 20–28 mm long, 7–10 mm wide, 9–11 veined, very light green before maturity. First lemma 15–19 mm long, glabrous, distinctly reddish-yellow; basal hairs very few to absent; awn rarely present; separating from pedicel by semiabscission. Second lemma 12–16 mm long, awnless. Second floret rachilla segment exceedingly short, ½ to 1½ mm, glabrous, separating from first floret by basifracture. Third floret 6–9 mm long, awnless. Third floret rachilla segment, 2–3 mm long, glabrous, separating from second floret usually by disarticulation.

Navarro is differentiated from other varieties of oats by two outstanding characters, namely, a distinct purplish bloom which covers the entire plant during the heading and ripening period and an exceedingly short second floret rachilla segment. The spikelet separates from its pedicel by semiabscission, similar to that of the Fulghum and some strains of the Burt variety. In this character Navarro is more or less intermediate between varieties of *Avena sativa* and *A. byzantina*. The second floret separates from the first by basifracture, that is, as in the Red Rustproof (Red Texas) variety, but differs markedly in having a very short second floret rachilla segment. The third floret usually separates from the first by disarticulation, and possesses a rachilla segment from 2 to 3 mm in length. Navarro is practically awnless. The color of the lemma is best described as reddish yellow, a slightly darker yellow than is found in the most intensive yellow varieties of *A. sativa*. The straw of Navarro has the reddish tinge which is so characteristic of red oat varieties, such as Red Rustproof and Fulghum. Navarro is highly resistant to the smuts of oats, including the physiologic races that attack red oats. The variety is susceptible to the oat rusts.

Because of its mixed characteristics some confusion may arise regarding the classification of the Navarro oat. On the basis of spikelet separation the variety is intermediate to varieties of *Avena sativa* and *A. byzantina*. On the other hand, in separation of the second floret from the first, Navarro is typical of the varieties belonging to *A. byzantina*. It is considered that this latter character identifies Navarro as belonging to *A. byzantina*. Spikelets and florets of Navarro are shown in Fig. 1.

So far Navarro has been very uniform, showing no off types except an occasional fatuoid. It offers some new and interesting characters for genetic studies. It will be most useful, however, in breeding for smut resistance in red oats, particularly in Fulghum and its strains in which smut has become rather prevalent during recent years.

Navarro is being extensively used in a breeding program for smut resistance in red oats by Coker's Pedigreed Seed Company of Hartsville, S. C. One of the plant breeders connected with this company, Mr. Geo. J. Wilds, Jr.,[8] has reported on the hybridization of Navarro and Fulghum for the development of smut-resistant strains of the Fulghum type.

[8]Wilds, Geo. J., Jr. Our extensive oat breeding work. Coker's Magazine Catalog, Published by Coker's Pedigreed Seed Co., Hartsville, S. C., 41–43. 1931.

Reed and Stanton[9] have recently shown the smut resistance of Navarro and its value as a differential host for the study of physiologic races of the oat smuts.

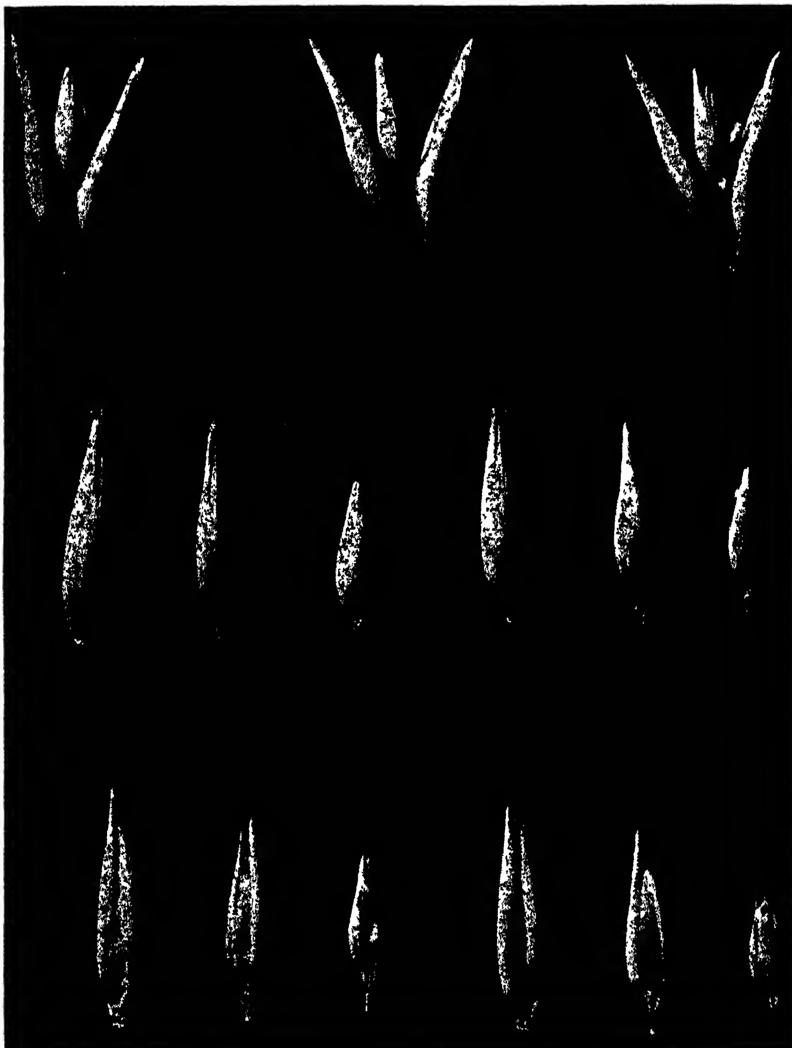

FIG. 1.—Spikelets and florets of Navarro oats.

It also has been crossed on several varieties by the Division of Cereal Crops and Diseases for studies on the inheritance of smut resistance and the development of smut-resistant strains of the Fulghum type.

[9]REED, GEORGE M., and STANTON, T. R. Physiologic races of *Ustilago levis* and *U. avenae* on red oats. Jour. Agr. Res., 44:147–153. 1932.

YIELD

Navarro has produced rather low yields of grain from both fall and spring seeding and can not be recommended for growing on farms. It has not been especially resistant to cold, although at the Arlington Experiment Farm, Rosslyn, Va., it has survived most winters. Few data are available on relative yields of Navarro. Some yield data on Navarro grown from fall seeding at the Arlington Farm have been published by Stanton, *et al.*[10] During the period from 1922 to 1925, inclusive, Navarro (C.I. No. 966) grown in plats produced an average acre yield of 41.0 bushels as compared with 69.6, 65.6, and 65.5 bushels for Lee (C.I. No. 2042), Winter Turf (C.I. No. 435-4), and Fulghum (C.I. No. 708), respectively, for the same period. In replicated nursery rows the average yields for these same varieties were 48.6, 71.8, 67.9, and 70.3 bushels, respectively, for the period from 1921 to 1925, inclusive.

At the Coastal Plain Experiment Station, Tifton, Ga.,[11] Navarro was grown from fall seeding in plats during the 7-year period from 1923 to 1929, inclusive, with an average yield of 22.8 bushels. For this same period Hastings (Hundred Bushel), a strain of the Red Rustproof variety, Fulghum, and Kanota (C.I. No. 839) produced average yields of 40.4, 30.0, and 27.4 bushels, respectively. Crown-rust infection in 1929 at Tifton reduced the yield of Navarro to 3.5 bushels, while Hastings (Hundred Bushel), with some resistance to crown rust, produced 41.4 bushels. At the Delta Branch Station, Stoneville, Miss.,[12] Navarro was grown in plats in 1923 and 1925 with an average yield of 43.1 bushels. The averages of Fulghum and Appler for the same years were 40.7 and 45.9 bushels, respectively.

Navarro as a spring-sown variety was grown in plats at the U. S. Dry Land Field Station, Lawton, Okla.,[13] during the period from 1925 to 1930, inclusive, with an average acre yield of 19.1 bushels as compared with 27.5 and 25.4 bushels for Kanota (C.I. No. 839) and Brunker (C. I. No. 2054), respectively, for the same period.

[10] STANTON, T. R., CHILDS, R. R., TAYLOR, J. W., and COFFMAN, F. A. Experiments with fall-sown oats in the South. U. S. D. A. Bul. 1481. 1927.

[11] Data from annual reports of cooperative cereal experiments in Georgia by R. R. Childs, filed in the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[12] Data presented by courtesy of the Delta Branch Station.

[13] Data presented through courtesy of W. M. Osborn, Superintendent U. S. Dry Land Field Station, Lawton, Okla.

PARENT-PROGENY CORRELATIONS IN COTTON[1]

J. F. O'Kelly and W. W. Hull[2]

The chief aims of cotton breeding are increased production, the alteration of certain characters, and increasing or maintaining the uniformity of all characters. The plant selection is the nucleus about which efforts to improve or maintain, characters center, whether the system of breeding be selection within a relatively pure variety or hybridization followed by selection. The importance, therefore, which the parent selection possesses in any breeding program has led to a careful study in many cases of the parent's characteristics sometimes without definite knowledge of the extent to which these characteristics would be reproduced in the progeny.

It is the purpose of this paper to report data which show how far certain plant selection characters in cotton can be used to indicate to what extent the same or other characters are reproduced in the progeny and, therefore, how carefully certain selection characters should be measured and to what extent labor and field space may be conserved by the elimination of undesirable selections before planting.

MATERIALS AND METHODS

The regular cotton breeding work of the Mississippi Agricultural Experiment Station afforded an opportunity for collecting the data presented here Since yield of lint cotton, lint percentage, and staple length are of chief importance in commercial cotton production, only data concerning them are reported. The amount of correlation was determined between each of the characters in the parent plant and the three characters in the progeny. Correlations which involved only one generation were not made.

The three varieties Trice, Miller, and Lone Star were used. At the beginning of the study they were somewhat lacking in uniformity, although not extremely so. During the years included in the study, most of the parent selections were taken from progeny rows, but some were occasionally taken from increase plats of promising strains. The selections made in the field were taken to the laboratory where the lint yield, lint percentage, and staple length were determined. A few of these were usually discarded because of low percentage or short staple. Those remaining were prepared for planting in progeny rows the following spring These progeny tests were always duplicated and the progeny data are averages of the two series or replications. The plants in the progeny rows were spaced 30 inches apart in order to reduce competition from neighbor plants and thus to make corrections for yield more dependable. Plant counts were made and yield corrections based on an average stand. Rows were about 100 feet in length. No selfing was done, but before planting the parent selections were grouped according to staple length and, in some cases, according

[1]Contribution from the Department of Agronomy, Mississippi Agricultural Experiment Station, State College, Miss. Received for publication June 23, 1932.
[2]Agronomist and Plant Breeder and Assistant Plant Breeder, respectively.

to lint percentage. This grouping reduced to some extent the effects of natural cross pollination.

It should be noted with reference to the correlations obtained that they are based on parent material which was selected for normal to high yield, normal to high lint percentage, and normal staple length. Had a random sample been used or had selection in opposite directions been practiced, different results might have been obtained. Trials with random samples were not made because of the difficulty of obtaining accurate yield results in the progeny test when parent plants having only a few seed are used. It is obvious that the use of of parent plants with only a few seed would result in an extremely poor stand and, although the yield were corrected to an average stand, the farther the actual stand varied from the average, the less accurate would the corrected yield be.

Staple length was determined by college students. The lint on 10 seeds from each selection was combed and measured in millimeters. The seeds were always taken from different locks. The average of the 10 measurements was used as the length for the selection. Samples of seed cotton were saved from the duplicate progeny rows and 10 measurements for each sample were made by each of two students. The average of the 40 measurements was used as the progeny length.

Lint percentage was determined by students. In the case of the selections a 10-saw gin and scales graduated to 0.1 gram were used. For the progenies a 20-saw gin and scales graduated to 0.01 pound were used. All of the selection was ginned at one time. The duplicate samples of the progenies were ginned separately.

RESULTS

The number of individuals of each variety for the different years is given in Table 1. The year mentioned in the table is the one in which the progeny was grown. The correlation coefficients for all characters are presented in Table 2.

TABLE 1.—*Number of progenies grown.*

Year	Trice	Miller	Lone Star
1925	76	77	—
1926	58	—	—
1927	78	118	76
1928	—	155	117
1929	—	189	138
1930	—	144	—

PARENT YIELD AND PROGENY YIELD

Only a few of these values approach significance. In fact, it is doubtful if any correlation existed which could be determined by these methods and under these conditions. Harland (3),[3] in studying inbred strains of Sea Island cotton, found a significant positive correlation ($r = .46 \pm .12$) between yield of parent strain and yield of daughter strain. Apparently there were only about 20 strains in-involved.

[3]Reference by number is to "Literature Cited," p. 118.

TABLE 2.—*Coefficients of correlation between parent and progeny characters in three varieties of cotton, 1925–30.*

Year of study	Progeny characters								
	Yield			Lint percentage			Staple length		
	Trice	Miller	Lone Star	Trice	Miller	Lone Star	Trice	Miller	Lone Star
				Parent Yield					
1925	.041±.08	.074±.08	——	.177±.08	.094±.08	——	.097±.08	—.214±.07	——
1926	.249±.08	——	——	.193±.09	——	——	.017±.09	——	——
1927	—.386±.07	—.050±.06	—.035±.08	—.601±.05	—.042±.06	.064±.08	—.258±.07	—.048±.06	—.225±.07
1928	——	—.178±.05	.270±.06	——	.062±.05	.261±.06	——	.064±.05	—.230±.06
1929	——	.091±.05	.081±.06	——	.128±.05	.120±.06	——	—.044±.05	—.101±.06
1930	——	—.047±.06	——	——	—.065±.06	——	——	.087±.06	——
				Parent Lint Percentage					
1925	.262±.07	.228±.07	——	.491±.06	.348±.07	——	.116±.08	—.240±.07	——
1926	.169±.09	——	——	.604±.06	——	——	—.060±.09	——	——
1927	.370±.07	.262±.06	.381±.07	.677±.04	.591±.04	.044±.08	.392±.06	—.171±.06	—.016±.08
1928	——	.353±.05	.279±.06	——	.804±.02	.691±.03	——	—.256±.05	—.325±.06
1929	——	.123±.05	.385±.05	——	.510±.04	.474±.04	——	—.279±.05	—.119±.06
1930	——	—.065±.06	——	——	.551±.04	——	——	.025±.06	——
				Parent Staple Length					
1925	—.026±.08	—.201±.07	——	—.118±.08	—.078±.08	——	.452±.06	.465±.06	——
1926	.473±.07	——	——	.033±.09	——	——	581±.06	——	——
1927	—.078±.08	.042±.06	—.486±.06	.164±.07	—.317±.06	—.107±.08	.626±.05	.655±.04	.664±.04
1928	——	—.264±.05	—.389±.05	——	—.172±.05	—.523±.05	——	.681±.03	.751±.03
1929	——	—.107±.05	—.028±.06	——	—.398±.04	—.174±.06	——	.661±.03	.290±.05
1930	——	—.114±.06	——	——	—.404±.05	——	——	.542±.04	——

The absence of significant correlation is attributed largely to variations in soil and rainfall. The inherent yielding capacity could more easily be obscured by environmental influences in the case of a single plant selection than in the case of the several plants of its progeny, or in any case where a number of plants are used. Likewise, varying amounts of rainfall during the growing period of different seasons would obscure the facts in case a group of strains was composed of both dwarf and vigorous growing types.

From each group of progenies several high-yielding strains were retained and increased. Massed material from each of these increase plats was harvested separately and used for further trial in new strain tests. This presented an opportunity to correlate progeny yields with new strain yields. Twenty-seven Trice strains gave a correlation of .341 ± .11; 56 Lone Star strains, .198 ± .09; and 75 Miller strains, .204 ± .07. The low values of these correlations between progenies and new strains were likely caused to some extent by the selection for further propagation of the strains yielding highest in the progeny-row tests. The low producers in the progeny-row tests were not propagated for further testing.

PARENT YIELD AND PROGENY LINT PERCENTAGE

Only two of these values can be considered significant. Lone Star in 1928 showed a very slight positive correlation, the value being .261 ± .06. In 1927, Trice showed a strong negative correlation, the value for r being —.601 ± .05. The conflict in these values may be due to seasonal or varietal differences. In either case, the conflict lessens their significance for practical breeding work.

PARENT YIELD AND PROGENY STAPLE LENGTH

Seven of the coefficients for parent yield and progeny staple length are negative and four are positive. None of the positive values can be considered at all significant and the negative values are probably not highly significant.

PARENT LINT PERCENTAGE AND PROGENY YIELD

In the group of coefficients between parent lint percentage and progeny yield only one is negative and it is not significant. Of the 10 positive values, 8 are at least three times their probable errors. While the correlation is not strong, the values are great enough and consistent enough to show positive correlation. Here is an indication that the lint percentage of the parent may be more dependable for predicting the progeny yield than is the parent yield.

PARENT LINT PERCENTAGE AND PROGENY LINT PERCENTAGE

Here the coefficients indicate that the lint percentage of the parent and that of its progeny are strongly correlated. The one exception is the value for Lone Star in 1927. It is very likely that significant correlation actually existed in this case but was obscured because of abnormal percentages. The mean percentage of the parent selections was 36.6. Four of these had percentages well above 40, while their

progenies had percentages below the mean of all progenies. The elimination of these abnormal percentages would have materially increased the value of r. Ginning was done by college students and, while mistakes were probably made in these and other cases also, it is likely that the determinations, as a whole, were as accurate as any breeder could hope to obtain.

PARENT LINT PERCENTAGE AND PROGENY STAPLE LENGTH

Hodson (4) and others (1, 2, 6, and 7) in studying plants within a generation of upland cotton found lint percentage to be negatively correlated with staple length. Kottur (5) reports these characters to be inherited independently in the Indian cottons with which he worked. The values obtained in this study, although not consistent, show a slight negative trend. This negative trend is more apparent when it is observed that the values for parent staple length and progeny lint percentage show an even greater negative trend.

PARENT STAPLE LENGTH AND PROGENY YIELD

The coefficients for parent staple length and progeny yield show a negative trend. There are only two positive coefficients. One of these, Trice in 1926, is significant. However, the preponderance of negative values, some of which are significant, appears to indicate a tendency for the selection of long lint to be followed by a slightly lower yield in the progeny.

PARENT STAPLE LENGTH AND PROGENY LINT PERCENTAGE

These coefficients also indicate negative correlation. All of the values except two are negative and these two are not significant Several negative values are significant and some show an amount of correlation great enough to have a practical bearing on breeding.

PARENT STAPLE LENGTH AND PROGENY STAPLE LENGTH

In all cases there is a strong positive correlation between staple length of the parent and that of the progeny. With methods for determining staple length as accurate as those used in this study, a breeder can use selections having desirable lengths and reasonably expect that these lengths will be approximated in the progenies.

These results are in line with those obtained by Harland (3). Studying 23 Montserrat strains of Sea Island cotton, he found a high positive correlation between staple length of the parent and mean length of the progeny. His value for r was $.72 \pm .07$.

It has been shown that parent lint percentage is positively correlated with progeny lint percentage. It will also be observed that parent staple length and progeny staple length are positively correlated. On the other hand, negative correlation exists between parent lint percentage and progeny staple length and between parent staple length and progeny lint percentage. These conditions consitute the problem with which cotton breeders have had to struggle and is the basis for the belief among some that long staple length and high lint percentage are "antagonistic". It appears, however, that some

progress has been made toward combining long staple with high percentage and further progress doubtless will be made when more is known about the inheritance of staple length and the physical and genetic aspects of the problem are separated.

SUMMARY AND CONCLUSIONS

Parent-progeny correlations involving lint yield, lint percentage, and staple length have been studied in connection with the regular cotton pedigree breeding work of the Mississippi Agricultural Experiment Station. Coefficients of correlation are reported for each of these characters in the parent selection with the same and each of the other two characters in the progeny.

No significant correlation was found to exist between the yield of the parent and the yield of the progeny. Causes for this lack of correlation were considered. In addition, the relation between progeny yield and new strain yield was measured. The tendency was weakly positive. These things indicate that the parent yield is not significant and they emphasize the need for well-controlled progeny and new strain tests to identify the high-producing strains.

No significant correlation was found between parent yield and progeny lint percentage. Parent yield seemed to be slightly negatively correlated with progeny staple length, although the evidence was conflicting and the values were not significant.

Lint percentage of the parent showed a weak positive correlation with the yield of the progeny and a weak negative correlation with staple length of progeny. Parent lint percentage was strongly correlated with progeny lint percentage.

Staple length of the parent seemed to be slightly negatively correlated with progeny yield and somewhat more strongly negatively correlated with progeny lint percentage. Parent staple length was strongly correlated with progeny staple length.

On the basis of these results and under similar conditions a cotton breeder would be justified in discarding, before planting, those selections which are undesirable in lint percentage and staple length. He could not, however, use selection yield to determine which should be discarded, provided normally productive plants were selected in the field. The yielding ability of cotton plants must be measured in progeny and later tests.

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HARD SEED IN KOREAN LESPEDEZA[1]

GORDON K. MIDDLETON[2]

Korean lespedeza (*Lespedeza stipulacea*), a relatively new crop, is receiving considerable attention from agronomists who find that it has a wide range of adaptation and uses. A factor which has undoubtedly contributed to the popularity of the crop is the ease with which stands are secured, either from new or from volunteer seedings.

In spite of the fact that growers are seldom disappointed in the stands obatined, there is a hard seed problem in lespedeza which needs to be better understood. This hard seed condition causes poor germination and obscures the true value of the seed when tests are made soon after harvest. Fortunately, this condition breaks down largely during the winter following ripening.

Hardness and after-ripening in other leguminous crop seed have engaged the attention of several investigators. In the case of alfalfa and of red, alsike, and white clovers a decrease in the hard seed content during the winter following ripening has been noted by Hopkins,[3] Rostrup,[4] and Woll[5]. As an example of the general trend, Woll found that hard seed in red, alsike, and white clovers decreased on the average from 16% in November to 9% in February, with no further decrease by May.

The work reported in this paper was planned to obtain information relative to the time of conducting tests with samples of Korean lespedeza in order to obtain the most favorable germination results. Also, to see to what extent the agricultural value of a sample of seed could be estimated on a basis of actual germination plus hard seed when tests were made early in the season.

MATERIALS AND METHODS

During the past 3 years the seed laboratory of the North Carolina Department of Agriculture has tested over 800 samples of Korean

[1]Contribution from the Division of Farm Crop Seed Improvement, North Carolina Agricultural Extension Service, Raleigh, N. C. Published with the approval of the Director of the North Carolina Agricultural Experiment Station as Paper No. 60 of the Journal Series. Received for publication June 28, 1932.

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[3]HOPKINS, ELIZABETH F. The behavior of the hard seed of certain legumes when subjected to conditions favorable to germination. Proc. Assoc. Off. Seed Anal. of N. Amer. 14th Ann. Meet., 46–48. 1923.

[4]ROSTRUP, O. Report of Danish seed control for 1896–97. Abstract in Exp. Sta. Rec., 10:53–54. 1898.

[5]WOLL, F. W. Scandinavian seed control stations. Abstract in Exp. Sta. Rec., 10:10. 1898.

lespedeza seed for germination for certified seed growers. A study of the reports on these various lots of seed, tested at different times, led to certain conclusions which have been checked by more detailed studies on a limited number of samples. Thirty well-matured samples from the 1931 crop and 5 from the 1930 crop were selected and used in the study here reported. All tests were made in an electric germinator at a temperature ranging between 25° and 30°C, the duration of the tests being 14 days. One hundred seeds were used as a germination sample and all tests were run in duplicate. The bulk samples were stored in the laboratory and kept dry throughout the winter.

EXPERIMENTAL RESULTS

In November 1931, 10 well-matured samples of Korean lespedeza were selected and tested at monthly intervals through March 1932. These samples were all from the same community and had been harvested during ideal weather conditions. The November tests showed a range in germination from 32 to 70%, and sufficient hard seed to make the total viable[6] seed in each sample over 90%.

The data show a definite increase in germination and a decrease in hard seed from November through January for each of the 10 samples. During February and March there was very little decrease in the hard seed content, the average for the 60-day period being 1.2% The range in germination and hard seed obtained each month, as well as the general seasonal trend as expressed by the average monthly results, are shown graphically in Fig. 1.

Evidence from the preceding crop indicates a further gradual decrease in the percentage of hard seed, even when stored dry in the laboratory. Five well-matured samples from the 1930 crop which showed an average of 10.8% hard seed when tested in the spring of 1931 showed 6.7% hard seed in March 1932.

A careful study of the data presented in Fig. 1 shows that during the early part of the season there is a rapid breakdown in the hardness of many of the seeds and that to obtain satisfactory germination results the tests should not be made before January. In many cases, however, it is desirable, to have an estimate as to the potential germination of a lot of seed earlier than this. The estimate can be checked by a second test later in the season if desired.

Several methods of estimating the agricultural value of hard seed in other legumes have been proposed, based either upon allowance for the germination of a certain part of the hard seed or upon the softening of the seed coat of the germination samples by chemical or mechanical methods. In the case of the 10 samples for which data are given in Fig. 1, it was found that from 59.3 to 86.5% of those seeds reported as hard in November germinated in March. From December to March the decrease was not so consistent, however, the percentage varying from 0 to 79.3.

[6]Actual germination plus hard seed is here spoken of as total viable seed. Duplicate lots of two samples of seed were left in the germinator for a total of 33 days during April and May 1932. There was no germination after the tenth day. On the thirty-third day those seeds remaining hard were removed, scarified with sand paper, and replaced. In 48 hours 100% of these hard seeds germinated in each sample.

On the basis of these data it is not possible to say that a definite portion, such as 50 or 75% of the seed reported hard in the fall would germinate by spring. In those samples which had over 40% hard seed at the time of the first test the decreases were fairly consistent, but in those samples which gave a relatively low percentage of hard seed at the time of the first test the decrease in the different

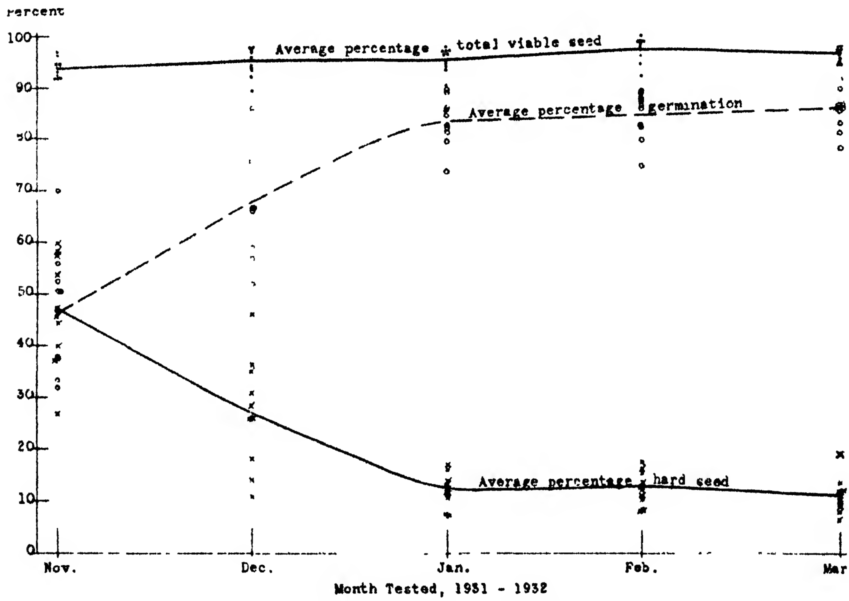

FIG 1.—Showing after-ripening in Korean lespedeza. The graphs represent the average results secured with 10 samples of seed tested at monthly intervals from November 1931 through March 1932. The monthly range in germination within the 10 samples is shown by small circles and that for hard seed by crosses. The percentage of total viable seed (germination plus hard seed) is also shown.

samples was inconsistent. This is due to the fact that after-ripening takes place faster in some samples than in others.

A simpler method of estimating the agricultural value of a sample of such seed would be on a basis of the total viable seed. Where this exceeds 90% the actual germination at planting time has always proved satisfactory, with the exception of a few lots of small seed taken out as screenings and which contained a high percentage of hard seed even when tested late in the spring. Samples containing too high a percentage of green, immature seed, or which have been weather damaged, have shown a low total viability, and can be detected in the fall as well as in the spring.

Of the samples discussed above, the lowest germination in March was 77.5%. Twenty other well-matured samples that had been tested by the seed laboratory in November and December and which showed total viable seed above 90%, were retested in March and the lowest actual germination obtained was 74%. Of the 30 samples tested

in March, only one showed a total viable seed content under 90% and that one was 88 5%.

For each of these 30 samples, then, one would have been correct had he assumed on a basis of the fall test that the spring germination would have been satisfactory. As a matter of fact, this has proved true for all well-matured, bright, plump samples of seed of this crop handled during 3 years of certification work.

SUMMARY

Ten well-matured samples of Korean lespedeza seed were tested at monthly intervals from November 1931 through March 1932. The results show a rapid decrease in the hard-seed content and a corresponding increase in germination for each sample from November through January, but with very little further change by March. The average percentages of hard seed for November, January, and March were 47.25, 12.25, and 11.05, and the average percentages of germination for the same periods were 46.70, 83.30, and 84.85, respectively. The data show that, if satisfactory results are to be obtained, germination tests should be delayed at least until January following harvest. This conclusion is substantiated by reports on several hundred samples of seed tested during the past 3 years.

The results of tests made in the fall of 1931 and in March 1932, on 30 samples of seed, show that when tests are made early in the season the total viable seed content (germination plus hard seed) is a more reliable guide to the agricultural value of the seed than is germination alone. For samples of well-matured, bright, plump seed, the deduction of 15% from this total, as determined in the fall, has proved a safe estimate of the actual germination obtained the following spring.

SOME FACTORS AFFECTING THE PALATABILITY OF PASTURE PLANTS[1]

A. B. BEAUMONT, R. E. STITT, and R. S. SNELL[2]

The practical importance of the palatability factor in the grazing of pastures is recognized by most herdsmen. However, most of the agronomical studies of pasture problems made in America have been concerned chiefly with the question of production. European workers appear to have given more consideration to the question of palatability, but pasture grasses important in Europe are not widely grown in the United States. Many workers on pasture problems have observed differences in edibility of different species of pasture plants grown under uniform conditions or the same species under different conditions; and some of these observations have been reported, but few organized attempts to determine the factors affecting palatability have been reported.

The palatability factor assumes special importance from the standpoint of species when selective grazing over large areas is practised, and from the standpoint of environment when soil amendments and fertilizers are used. This factor deserves special consideration in the pasture regions of the northeastern United States, where, on account of increasing use of the Hohenheim system or a modification of it, the seeding of tillable pastures is becoming more common; and especially because in this system rotational grazing is practised which permits the grass to grow taller than in many pastures continuously grazed.

REVIEW OF LITERATURE

White, *et al.* (8)[3] summarized some observations of palatability of grasses made on the Preswick pasture at the Cornell University Agricultural Experiment Station as follows: "The order of palatability of the various grasses used in this pasture seems to be as follows: Smooth brome, timothy, meadow fescue, meadow foxtail, orchard grass (when young), Kentucky bluegrass, and redtop. The cattle have shunned the redtop wherever it grew, whether alone or in mixtures." They also pointed out that grass on plots which received nitrate of soda and lime were quite closely grazed except where redtop was the chief grass.

Piper (6), however, quotes results of a Cornell experiment, presumably those of the Preswick pasture, in which he reverses the order of timothy and Kentucky bluegrass. Further (page 177), he states that Kentucky bluegrass "is very palatable to all classes of livestock,

[1]Contribution from the Department of Agronomy, Massachusetts Agricultural Experiment Station, Amherst, Mass. Contribution No. 143 of the Massachusetts Agricultural Experiment Station. Received for publication June 11. 1932.

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[3]Reference by number is to "Literature Cited," p. 128.

much more so than any other grass so capable of maintaining itself. It is distinctly exceeded in palatability only by smooth brome grass."

Sutton, *et al.* (7), points out that all cattle eat timothy greedily, and horses manifest especial fondness for it.

Davies (3) reported observations of the palatability of certain clovers and grasses to sheep. He ranked them as follows: Red, white, and alsike clovers, 100; timothy, 95; orchard grass, 88; perennial rye, 86; meadow fescue, 61; Phalaris (*nodosa* and *arundinacea*), 40; red fescue, 35.

Orr (5) cites difference in mineral content as an important factor in palatability. According to his data palatable grass contained more N, Ca, P, K, Na, Cl, and Si-free ash, but less fiber, than did unpalatable grass (species not mentioned).

Wilkins and Hughes (9) have recently reported an experiment in which the palatability of certain species of grasses used for pasturage was tested. Canada bluegrass, smooth brome, and timothy were preferred. Reed canary, Kentucky bluegrass, redtop, tall meadow oat, slender wheat, crested wheat, and rough stalked meadow were eaten moderately and about equally. Orchard grass and meadow fescue ranked low in palatability, and sheep's chewing's, and red fescue were scarcely touched.

Many workers have observed that cattle almost invariably eat fertilized grass in preference to unfertilized. Beaumont (2) has reported this in case of experiments with upland pastures, and noted that plots which received lime in addition to fertilizer were better grazed than those which received fertilizer only. Further, it was shown that the grass from the limed plots was richer in CaO than that from unlimed plots.

At the Massachusetts Experiment Station, in an experiment with the Hohenheim pasture system, it has been observed that grass on fertilized plots was more closely grazed than on the unfertilized plot; and Archibald (1) has shown that the fertilized grass contained considerably more nitrogen, calcium, and phosphorus than did the unfertilized grass during most of the growing season.

Montgomery (4), however, states that no relation has been found between chemical composition and palatability. He further states that generally the better grasses have softer and more pliable leaves and stems.

From this brief review of the literature it is evident that species and soil environment, particularly the environment created by the use of fertilizers, are important factors determining or affecting the palatability of pasture plants. Why one species differs from another in palatability or just how the soil environment manifests itself through palatability is not known. The problem is obviously quite complicated and difficult of solution. It is doubtful if such a subtle quality as palatability can ever be resolved into its elements or expressed in exact physical or chemical terms.

OBJECTIVE AND PLAN OF EXPERIMENT

This experiment was planned to furnish further information as to the palatability of plant species most commonly used for permanent

and semi-permanent pastures in the northeastern United States, under uniform and differential fertilizer treatments. It was planned to determine certain chemical and physical characteristics suspected of being associated with differences in palatability.

In the main experiment, designated as A, pure seedings of white clover (*Trifolium repens*), timothy (*Phleum pratense*), redtop (*Agrostis alba*), and Kentucky bluegrass (*Poa pratensis*) were made in July 1929. Plots were 10 x 10 feet and duplicated. Fertilizer treatments per acre were as follows:

A No fertilizer

B. 45 lbs. P_2O_5; 45 lbs. K_2O (equivalent to 750 lbs. 0-6-6 mixed fertilizer)

C. 45 lbs. P_2O_5; 45 lbs. K_2O + 30 lb. N (equivalent to 750 lbs. 4-6-6)

D 45 lbs. P_2O_5; 45 lbs. K_2O + 60 lbs. N (equivalent to 750 lbs. 8-6-6)

E. 45 lbs. P_2O_5; 45 lbs. K_2O + 90 lbs. N (equivalent to 750 lbs. 12-6-6)

Phosphorus was supplied in 16% superphosphate, potassium in muriate of potash, and nitrogen in nitrate of soda. Each plant species was given each of the fertilizer treatments.

As a minor supplementary experiment, known as B, the following grass species of German origin were sown in small plots near the area occupied by the main experiment: English rye (*Lolium perenne*), redtop (Fioringras, *Agrostis alba capillaris*), Italian rye (*Lolium italicum*), meadow fescue (2 strains, *festuca pratensis*), timothy (*Phleum pratense*), Reed canary (*Phalaris arundinacea*), red fescue (*Festuca rubra*), and yellow oat (*Avena flavescens*). These plots were uniformly fertilized.

Both experiments were conducted on a very fine sandy loam soil formed by deposition in shallow, quiet water. The soil is retentive of moisture and more fertile than most Massachusetts upland soils. It is an ideal grass land.

RESULTS OF THE EXPERIMENT

In the spring of 1930 the area containing both sets of plots was enclosed by a fence, and two young Holstein milch cows were turned in May 17. At that time the growth of grass was 4 to 6 inches high. The order of preference in Experiment A was as follows: 1st choice, white clover; 2d choice, timothy; 3d choice, redtop; and 4th choice, bluegrass. In this experiment there was no observable difference in choice among plots with different fertilizer treatments.

On the supplementary planting, Experiment B, the order of choice was as follows: 1st, timothy; 2d, redtop; 3d, Italian rye; 4th, English rye; 5th, yellow oat; and 6th, meadow fescue. Red fescue was grazed very slightly and Reed canary not at all. A second grazing test conducted on these plots in the latter part of July showed results similar to those obtained in May. The plots were kept mown during the rest of the season of 1930.

On May 11, 1931, two aged Holstein cows were turned on the plots. The grass was 2 to 4 inches high, somewhat younger than it was when

first pastured in 1930. The cows showed practically no choice among species, but they showed preference for the plots which received medium and high nitrogen in the fertilizer; except for the clover plots, which, if anything, were slightly less well grazed where nitrogen was applied. They were returned to the plots June 3, and this time the choice of 1930 with respect to species was duplicated. Again preference was shown for grasses but not clover, which received nitrogen, some slight preference being shown for high-nitrogen grass. Again, early in August, the cows were returned to the plots. The choice of the preceding time was duplicated, although all grasses had then passed the blossoming period and had apparently deteriorated, redtop being badly infested with a leaf spot (*Helminthosporium demateoideum*).

During the summer of 1930, R. C. Foley, studying the botanical composition of the flora of plots used in an experiment with the Hohenheim system at this Station, observed that milch cows showed a decided preference for mixed seedings which contained high percentages of timothy and redtop as compared with the plot which had a high percentage of bluegrass. Similar observations were made in 1931.

About August 1, 1931, samples were taken from the different species of grasses in experiment A which had received the medium amount of nitrogen and were subjected immediately to a breaking test in the laboratory. The equipment used for this test was improvised from apparatus designed for determining the penetrability of soils. A sharp steel blade was substituted for the stylus used with soils, and water for sand for measuring pressure. Fifty individual blades of each grass species were subjected to the test, thus reducing considerably the probable error. The breaking strength of each blade was determined in grams, and its perimeter measured in millimeters at the cross-section of the break. Breaking strength per millimeter of perimeter was calculated by dividing breaking strength by perimeter. The results are summarized in Table 1.

TABLE 1.—*The breaking strength of some pasture grasses expressed in grams per millimeter of perimeter, mean of 50 trials.*

Grass	Breaking strength
Timothy	58.62±1.20
Redtop	52.87±1.32
Kentucky bluegrass	92.60±2.67
Red fescue	147.90±4.85
Reed canary	42.29±0.84

DISCUSSION

The results of observations of the palatability of the species are somewhat contrary to the prevailing opinion of agronomists. It was expected that white clover would prove the most palatable of the species tested, but it was hardly expected that Kentucky bluegrass would be surpassed by both timothy and redtop. However, a careful study of the literature shows that it is what should be expected,

except that according to observations of White at Cornell, redtop should have been the least palatable. Our observations are also in agreement with the observations of some farmers respecting Kentucky bluegrass.

The stage of growth seems to be an important factor in the palatability of grasses. For example, in 1931, the cows were turned on the plots 6 days earlier than in 1930. Besides that difference, the grass did not seem as advanced in 1931 as in 1930 for the same date. The cows did not discriminate between the species of the young early grass 2 to 4 inches high as between the same species somewhat more advanced toward maturity. Kentucky bluegrass flowers in this section one to two weeks earlier than redtop and two to three weeks earlier than timothy. From this relationship it would appear that the nearer a grass approaches maturity the less palatable it becomes.

The data on breaking strength are interesting. It is thought that they give numerical expression to the toughness of the grass, and it appears likely that, other factors being favorable, toughness may be a deciding factor in palatability. It should be noted, however, that Reed canary grass, one of the least palatable grasses in our test, was the least tough. The breaking strength varied almost inversely with the width of the leaf, the average width in millimeters of 50 blades used in the test being Reed canary, 5.07; timothy, 4.11; redtop, 3.40; Kentucky blue grass, 2.25; and red fescue, 0.76.

Thus it appears from the studies here reported that species is a very important factor in determining the palatability of grasses. Further, the data indicate that the physical property of toughness may be of considerable importance. Stage of growth is a factor. Probably, it will be found that chemical composition plays an important rôle in conjunction with physical properties, and that these together largely account for species differences.

SUMMARY AND CONCLUSIONS

A study has been made of some factors thought to affect the palatability of pasture grasses. Timothy, redtop, Kentucky bluegrass, and white clover have been grown under differential fertilizer treatments. In addition, English rye grass, Italian rye grass, timothy, redtop, meadow fescue, red fescue, yellow oat grass, and Reed canary grass have been grown under uniform fertilizer conditions. Milch cows were allowed to graze selectively over the plots, and samples of the crops were taken for chemical and physical examination. The results are summarized as follows:

1. Plant species were selected by milch cows in the following order: Experiment A, 1st, white clover; 2d, timothy; 3d, redtop; 4th Kentucky bluegrass. Experiment B, 1st, timothy; 2d, redtop; 3d, Italian rye grass; 4th, English rye grass; 5th, yellow oat grass; 6th, meadow fescue; 7th, red fescue; and 8th, Reed canary, the last two hardly touched.

2. Stage of growth is a factor which affects palatability. The preceding order of choice prevailed when grass was 4 to 6 inches high. When it was 2 to 4 inches high little discrimination was shown.

3. The first year after seeding practically no difference in palatability could be referred to difference in fertilizer application, but the second year grass which had received nitrogen and minerals was grazed more than that which had received only minerals or no fertilizer. Grass which received high nitrogen appeared to be slightly more palatable than that which received medium or low amounts.

4. Toughness of grasses was determined by breaking or cutting the individual blades of grass. By this method red fescue and Kentucky bluegrass proved significantly tougher than timothy and redtop. The former were also less palatable than the latter; but Reed canary, one of the least palatable, was the least tough.

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CHANGES IN VOLUME THAT OCCUR WHEN DRY SOILS ARE WETTED WITH WATER AND WITH CHEMICAL SOLUTIONS[1]

George Bouyoucos[2]

It is well known that soils containing colloids swell when they take up water. In other words, there is an increase in their apparent volume. However, the question is does the absolute volume of soil and water, considered together, increase or decrease when the soils in dry condition are brought in contact with water. If the absolute volume increases, it indicates that the swelling is greater than the volume of water taken up; if the absolute volume decreases, it indicates that some of the water adsorbed in the swelling process has been compressed; if, on the other hand, the absolute volume remains unchanged it would logically seem that the swelling of the soils is equal to the volume of water taken up and that the soils have not expanded additionally, nor has the water contracted or been compressed. It is the object of this paper to present experimental results bearing on the changes in volume that take place when dry soils are wetted with water and with different chemical solutions.

METHODS AND PROCEDURE

The method developed and finally adopted for measuring changes in absolute volume when dry soils are wetted with liquids, consists in placing the equivalent of 30 grams of dry soil in a dilatometer, drying it in an oven at 110°C for 24 hours, then quickly but gently pouring into the dilatometer sufficient carbon tetrachloride to cover the soil. With a glass rod the soil mass is stirred until the air is all displaced by the carbon tetrachloride. The dilatometer is then filled with water or with the chemical solution, stoppered, and placed in a constant temperature bath. After equilibrium is attained the volume reading is taken and the dilatometer is tilted allowing the liquid and the soil to come into intimate contact. The readings before and after the soil and liquid are mixed show the difference, if any, that occurs in the volume.

The method works remarkably well. Since carbon tetrachloride is heavier than water, the latter can be prevented from coming into contact with the soil before the desired time. Carbon tetrachloride penetrates the soil mass sufficiently to displace completely all the air present and the water in turn displaces the carbon tetrachloride so that the reaction taking place between the soil and liquid is the same as though the soil never were treated with carbon tetrachloride, or as if this liquid were not present. In view of these facts, the method is accurate, simple, practical, and is probably most exceptional for investigations of the type herein described.

[1]Contribution from the Department of Soils, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 98 (n.s.). Received for publication June 8, 1932.
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That the presence of carbon tetrachloride has no adverse effect on the reaction between the soil and water or chemical solutions is supported by experimental data which show that if water is added to soils in the dry condition while they are immersed in carbon tetrachloride, the amount of heat evolved is practically the same as in water alone (1)[3]. This interesting fact indicates that the specific attraction of the soil for water is not destroyed by the presence of the carbon tetrachloride.

The dilatometer apparatus used is shown in Fig. 1. It consists of two parts, the bulb and the stem. The bulb has a capacity of 100 cc. The stem is a 2-cc pipette which is calibrated to 0.01 cc and the readings can be estimated to about 0.003 cc. The mouth of the bulb is stoppered with cork and smeared with tallow.

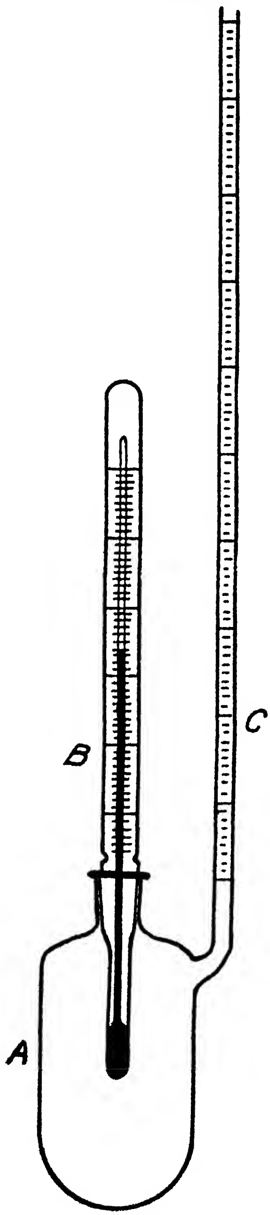

FIG. 1.—Dilatometer for measuring volume contraction of soils when wetted with water.

EXPERIMENTAL DATA

In Table 1 are presented the volume changes that took place when a large number of representative soil types in the oven-dry condition were wetted with water and with normal solutions of $MgCl$, KCl, $CaCl_2$, $BaCl_2$, $LiCl$, $SrCl_2$, $NaCl$, NH_4NO_3, and KOH. The volume change is expressed in cc per 100 grams of soil.

The results in Table 1 show conclusively, that when dry soils are wetted with water and with various chemical solutions the absolute volumes decrease, the magnitude of the changes ranging from 0.110 cc in Plainfield sand to 1.830 cc in Fargo clay loam and to 4.876 in muck per 100 grams of soil.

Probably the most surprising fact is that, with the exception of KOH, all chemical solutions induce the same volume decrease as does water. The volume contraction with KOH is only a fraction of that resulting when the other chemical solutions are used. In fact, in the case of two soils, Davidson loam and Nipe clay, there is even a slight expansion in volume. The probable explanation for this contrary behavior of the soils treated with KOH will be presented subsequently.

[3]Reference by number is to "Literature Cited," p. 133.

TABLE 1.—*Decrease in cc in absolute volume that takes place when 100 grams of oven-dry soil are wetted with water and with different chemical solutions.*

Soil	H_2O	MgCl	KCl	$CaCl_2$	$BaCl_2$	LiCl	$SrCl_2$	NaCl	NH_4NO_3	KOH
Plainfield sand, surface	0.110	0.105	0.099	0.101	0.100	0.098	0.978	0.103	0.104	0.028
Putman silt loam, surface	1.300	1.362	1.359	1.298	1.352	1.295	1.389	1.380	1.250	0.388
Clarion silt loam, surface	1.465	1.430	1.428	1.416	1.498	1.410	1.496	1.415	1.410	0.378
Colby silt loam, surface	0.865	0.895	0.880	0.875	0.891	0.878	0.868	0.865	0.893	0.266
Cecil clay loam, subsoil	0.398	0.401	0.395	0.391	0.389	0.396	0.388	0.373	0.399	0.139
Barnes loam, subsoil	0.560	0.573	0.599	0.606	0.583	0.633	0.616	0.625	0.635	0.056
Davidson loam, subsoil	0.486	0.495	0.483	0.483	0.438	0.433	0.449	0.476	0.462	0.076
Nipe clay	0.556	0.540	0.510	0.520	0.535	0.540	0.540	0.593	0.555	0.036
Capay clay adobe	0.849	0.850	0.861	0.858	0.852	0.868	0.869	0.880	0.900	0.149
Almont adobe, 0–10 inches	1.150	1.120	1.165	1.152	1.120	1.100	1.145	1.082	1.150	0.352
Fulton clay, subsoil	0.616	0.649	0.658	0.660	0.662	0.651	0.640	0.583	0.635	0.066
Houston clay, subsoil	1.625	1.510	1.515	1.400	1.590	1.515	1.500	1.683	1.630	0.380
Haldemand clay, subsoil	1.000	0.932	0.906	0.982	0.932	1.015	0.932	1.000	0.992	0.100
Lake Charles clay, subsoil	0.932	0.956	0.892	1.060	0.916	0.939	0.932	0.916	0.960	0.150
Fargo clay loam, subsoil	1.830	1.682	1.580	1.560	1.715	1.845	1.780	1.730	1.834	0.333
Black clay adobe	1.385	1.250	1.220	1.300	1.300	1.400	1.382	1.282	1.328	0.066
McKenzie clay	1.120	1.112	1.095	1.135	1.098	1.103	1.116	1.128	1.100	0.066
Muck	4.876	4.930	4.720	4.689	4.890	4.930	4.650	4.730	4.850	—

RELATIONSHIP BETWEEN VOLUME CONTRACTION WHEN SOILS ARE WETTED AND CLAY CONTENT

It will be of interest to know what relationship the volume contraction bears to the clay content of the different soils. The data in Table 2 afford such a comparison.

The data in Table 2 show that, although the volume contraction tends to increase with the clay content, the relationship is by no means regular and close. For instance, surface Putman silt loam, surface Clarion silt loam, etc., contain much less clay than subsoil Haldemand clay, subsoil Davidson loam, adobe Capay clay, etc., and yet the latter soils show considerably less volume contraction than the former.

TABLE 2.—*Relationship between volume change and clay content of soils.*

Soils	Decrease in volume, cc	Clay, 0.005–000 mm, %	Fine clay, 0.002–000 mm, %
Plainfield sand	0.110	8.8	6.9
Putman silt loam, surface	1.380	24.2	20.5
Clarion silt loam, surface	1.141	24.3	21.8
Colby silt loam, surface	0.865	25.5	19.0
Cecil clay loam, subsoil	0.373	40.2	38.7
Barnes loam, subsoil	0.625	32.2	29.2
Davidson loam, subsoil	0.476	71.2	69.1
Nipe clay	0.593	—	—
Capay clay adobe	0.880	63.2	56.9
Almont adobe, 0–10 inch	1.082	51.8	45.9
Fulton clay, subsoil	0.583	68.0	66.5
Houston clay, subsoil	1.683	65.8	61.3
Haldemand clay, subsoil	1.000	85.6	77.4
Lake Charles clay, subsoil	0.916	42.4	38.9
Fargo clay loam, subsoil	1.730	66.8	58.2
Black clay adobe	1.282	55.9	52.7
McKenzie clay	1.128	76.1	71.9
Muck	4.876	—	—

Referring again to the experimental data in Table 1, two hypotheses may be offered to explain the phenomenon of the volume contraction, *viz.*, chemical hydration and physical compression of water. Of the two, the physical compression is probably the more important and is probably, responsible for most, if not for the entire, volume contraction. It is conceived that the water adsorbed by the soil particles is compressed (2, 3, 4) and its volume is thereby diminished.

On the above hypothesis the smaller volume contraction with KOH as compared to that with water and with the rest of the chemical solutions can be explained by assuming that the KOH molecules, having a great affinity for water, do not allow much water to be adsorbed by the soil particles and compressed. In other words there is a competition between the soil and the KOH molecules for the water and it seems that at the concentration used the affinity of the KOH molecules for the water just about equals that of the soil. The fact that the volume contraction shows no special variation with the

soils of different chemical composition and reactions lends support to the above explanation.

It is seen, therefore, that when soils are saturated with water or with chemical solutions and swell and increase in volume, that this increase in volume is only apparent, not real; in the real or absolute volume of soil plus liquid there is a decrease.

SUMMARY

An investigation was conducted to ascertain the volume changes that take place when oven-dry soils are wetted with water and with different chemical solutions.

It was found that the original or absolute volume of the soils and liquids considered together decreases when the soils are brought into intimate contact with the liquids.

The volume contraction varies with the different soils, being greatest in clays and in soils with high organic matter content.

With the exception of KOH solution, the volume contraction in all the chemical solutions used was the same as that in water, in any given soil. That in the KOH was greatly less.

The volume contraction is probably due to the compression of the water adsorbed by the soils.

When soils are saturated with water or chemical solutions and swell and increase in volume, this increase in volume is only apparent and not real. In the real volume there is a decrease.

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THE NATURE OF PHOSPHATE FIXATION IN SOILS[1]

M. C. FORD[2]

This investigation was undertaken for the purpose of determining the nature of phosphate fixation in soils with special regard to the processes involved and the products formed when soluble phosphates are added. The study was suggested by certain results previously obtained and reported by the writer (7).[3] It was shown that when superphosphate is applied to different soils, the phosphorus becomes fixed, to some extent, in forms not readily soluble in sulfuric acid of pH 3.0. This takes place to a much greater extent in some soils than in others. This fixation ranged from 50 to 91% under field conditions when the phosphate was applied without lime and from 15 to 90% when applied with lime. Lime was more effective in reducing phosphate fixation in relatively insoluble forms in some soils than in others. These results, together with certain known geological characteristics of the soils studied, caused the writer to believe that a further study of phosphate fixation, with special regard to the processes involved and the products formed, might explain some of the differences in the response of soils to phosphate fertilization.

REVIEW OF LITERATURE

A review of the literature shows that phosphates may be fixed by soils in several different forms. Many years ago Gerlach (13) demonstrated the formation of di- and tri-calcium phosphate crystals from a solution of mono-calcium phosphate when calcium carbonate was added. He also demonstrated the formation of di-calcium phosphate crystals and ferric phosphate when a solution of mono-calcium phosphate and a suspension of ferric hydroxide were mixed. He states that freshly precipitated ferric hydroxide was more active than old precipitates or dried precipitates. Gerlach concluded that when superphosphate is added to a soil, the phosphorus becomes fixed as calcium, magnesium, ferric, and aluminum phosphates, and, when the calcium and magnesium phosphates dissolve in carbonated water, more ferric and aluminum phosphates are formed in the presence of the sesquioxides.

Later, Ellett and Hill (5, 6) repeated the work of Gerlach and confirmed his results. They also mixed ferric and aluminum hydroxides with water solutions of mono-calcium phosphate and superphosphate. After the mixtures had gone to dryness, they determined the solu-

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. This work was supported by a fellowship grant from the Ruhm Phosphate and Chemical Company, Chicago, Illinois. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication June 27, 1932.

[2]In charge of Agricultural and Biological Sciences, State Teachers' College, Bowling Green, Kentucky. The writer wishes to express his appreciation for the helpful suggestions and criticisms tendered by Professor Emil Truog, under whose general supervision this investigation was conducted. He also wishes to acknowledge his indebtedness to Prof. R. C. Emmons and to Prof. A. N. Winchell for valuable suggestions.

[3]Reference by number is to "Literature Cited," p. 143.

bility of the phosphorus in 0.2 N HNO_3 and other solvents. The availability of the phosphorus to plants was also determined. Satisfactory plant growth was secured with these materials. The acid extracted about one-half of the phosphorus from these phosphates. Ellett and Hill also applied a water solution of superphosphate to samples of several soils. After the soils became dry they were extracted with 0.2 N HNO_3 to determine the nature of phosphate fixation. From 17 to 95% of the phosphorus was fixed in forms not soluble in this solvent.

Fraps (8) made extensive studies on fixation of phosphates in soils. He found that fixation occurs in the presence of 0.2 N HNO_3, that this fixation is roughly proportional to the total iron and aluminum oxides, and that soils containing over 10% of these oxides absorbed over 50% of the phosphorus added. Fixation from a solution of 0.2 N HNO_3 ranged from 5 to 94%. He states that probably only a small percentage of the oxides of iron and aluminum in the soil has high fixing power.

It has been shown by Truog (24) that at least a portion of the phosphorus in precipitated ferric and aluminum phosphates is available to plants. Since phosphorus is apparently fixed in soils to some extent in forms very difficultly available to plants, it seems that it must be fixed in forms less available than ordinary precipitated ferric and aluminum phosphates.

More recently, Fraps (11) studied the fixation of phosphorus by soils and minerals from water solutions. In the case of the soils, he found that fixation increased with increases in time and temperature. In the case of the minerals, as in the case of soils, he assumed that whatever phosphorus was no longer in solution was fixed and he, therefore, did not distinguish between fixation of different kinds. He found some degree of fixation by all of the minerals studied. He states that none of the minerals examined showed as high fixing power as some soils, although the amounts of the minerals used were in excess of what might be expected to be present in soils.

Doughty (4) has shown that ferric and aluminum phosphates hydrolize at a reaction range of pH 6.0 to 7.0, releasing phosphorus to the soil solution. Calcium phosphate was formed at pH 7.0 and did not hydrolize at higher pH values.

Fixation of phosphorus by the organic matter in the soil has received considerable attention. According to the results of Fraps (9), Stewart (22), and Doughty (3), this is probably rather small in most cases.

GENERAL PLAN AND METHOD OF STUDY

It is evident from a review of the literature and the writer's previous investigation (7) that when soluble phosphates are applied to the soil they may be fixed not only as tri-calcium phosphate and ordinary ferric and aluminum phosphates, which are quite readily available to plants, but also in a form or forms difficultly available to plants. It was the purpose of this investigation to determine, if possible, the nature of this latter form of fixation.

Of the mineral substances which are common in soils, there seemed

to be a possibility that either hematite (Fe_2O_3), Goethite (limonite) ($Fe_2O_3.H_2O$), or bauxite ($Al_2O_3.XH_2O$) might fix phosphates in difficultly available forms. The hematite and Goethite were crystalline and showed on X-ray analysis true patterns of these substances. The water content of the Goethite was 11%, of the bauxite 31.6%. The latter was probably largely Gibbsite ($Al_2O_3.3H_2O$). The presence of these minerals in soils has long been recognized, hematite being the predominant coloring matter in red soils and Goethite (limonite) and bauxite, according to Leith and Mead (16), appearing as products of the laterization process.

Soils of the Kentucky soil experimental fields, previously described (7), were used. Fertility treatment and crop-yield data have been given by Roberts (21). A summary description of these soils is included in Table 1.

In the fixation studies with soils, 1-gram samples were placed in 100-cc beakers with 25 cc of water and a solution of mono-calcium phosphate. The beakers were placed under a hood and brought to dryness in 12 hours at 25° to 30°C. In the case of the minerals, 0.1-gram samples, ground in an agate mortar to the consistency of silt, were similarly treated. Samples of the minerals were also placed in 250-cc Erlenmeyer flasks with 100 cc of a very dilute solution of H_3PO_4. The flasks were equipped with reflux condensers and digested, some at 40°C for 4 weeks and others at 85° for 6 to 8 days. The progress of fixation was determined by testing a 1 cc aliquot of the solution for phosphorus.

The solvent used to determine the extent and nature of phosphate fixation was 0.002 N H_2SO_4 buffered with K_2SO_4 to pH 3.0. In certain cases where a saturated solution of Ca $(OH)_2$ was added, 0.003 N H_2SO_4 buffered with K_2SO_4 to pH 3.0 was used. Samples of the dry soil were placed in 1-liter shaker bottles with 500 cc of the solvent and shaken. Aliquots were taken at intervals of 2 hours until equilibrium was reached, filtered, and the phosphorus content determined by the modified Denigès method of Truog and Meyer (25). In the case of the minerals which were digested in Erlenmeyer flasks, the suspension was filtered at the end of the digestion period, the residue washed with water to a volume of 200 cc, and the phosphorus determined in an aliquot of the filtrate. The residue on the filter paper was then transferred to a bottle, the solvent added, and an extraction made to determine the solubility of the fixed phosphorus. The residues, after the acid extraction, were subjected to X-ray analysis to determine the nature of the phosphate formed.

The effect of heat on the capacity of soils and minerals to fix phosphorus in relatively insoluble forms was determined by means of heating the samples in an electric muffle furnace and then testing the capacity of these samples in the manner just described. Some of the heated samples of minerals were subjected to X-ray analysis.

FIXATION BY SOILS

To determine the relative capacity of soils to fix phosphates in relatively insoluble forms, the soils were tested under controlled conditions already described. The results are given in Table 1.

TABLE 1.—*The power of soils to fix phosphorus in difficultly available forms and the amount of lime water required to prevent this form of fixation.**

Source of soil	Description of soil	Phosphorus fixed, %	Lime water required per gram of soil to stop fixation, cc
Berea field	DeKalb silt loam	50	15
Campbellsville field...	Silt loam (unmapped)	55	15
Russellville field... .	Decatur silt loam	35	7
Greenville field.. .	Tilsit silt loam	55	20
Fariston field . .	Silt loam (unmapped)	55	25
Mayfield field.. ...	Memphis silt loam	50	12

*Fifty p.p.m. of phosphorus added as $CaH_4(PO_4)_2$ to 1-gram samples of soil.

These results show that the Russellville soil has a relatively low capacity to fix phosphorus in relatively insoluble forms. The Berea and Mayfield soils have intermediate capacities and the Campbellsville, Greenville and Fariston soils have high capacities in this respect. As pointed out, the differences under field conditions of prolonged fixation are much greater. However, the differences shown in Table 1 are believed to be significant in view of the short time allowed for fixation to occur. Fraps (11) has shown that phosphate fixation increases with increases of time and temperature.

EFFECT OF CALCIUM HYDROXIDE ON FIXATION

To determine the influence of calcium hydroxide on the fixation of phosphorus in relatively insoluble forms by soils, increasing amounts of a saturated solution of $Ca(OH)_2$ were added until complete recovery of the applied phosphorus was obtained. The results are given in Table 1.

These data show that the amounts of $Ca(OH)_2$ required to prevent the formation of relatively insoluble phosphates are much larger for some soils than for others. As shown in Table 1, the soils requiring the larger amounts of $Ca(OH)_2$ possess the higher capacities to fix phosphates in relatively insoluble forms. It seems that a saturated solution of $Ca(OH)_2$ might be used to determine the relative capacities of soils to fix phosphorus in relatively insoluble forms.

FIXATION BY PURE MINERALS

The reasons for selecting certain minerals and the method of treating these in fixation studies have already been given. Phosphorus was added both as mono-calcium phosphate and as H_3PO_4 in very dilute solution to 0.1-gram samples and fixation was allowed to proceed for 12 hours at 35°C. Extractions were then made in the regular way for a 4-hour period. The results are given in Table 2.

The data given in Table 2 show that hematite does not fix phosphorus, but that the hydrated oxides of both iron and aluminum fix phosphorus in appreciable amounts in forms not soluble in H_2SO_4 of pH 3.0.

In order to study the effect of temperature and time on the fixation of phosphates by minerals, 0.1-gram samples of hematite and Goethite were placed in Erlenmeyer flasks, together with 17.4 mgms of phosphorus as H_3PO_4 in a dilution of 100 cc. The flasks and

TABLE 2.—*Fixation of phosphorus by pure minerals, using 0.1-gram samples.*

Minerals	Amount of phosphorus fixed	
	2 mgms phosphorus added as $CaH_4(PO_4)_2$, %	8 mgms phosphorus added as H_3PO_4, %
Hematite	0	0
Goethite	55	40
Brown Goethite	25	15
Bauxite	20	25

contents were then kept at various temperatures for certain periods as indicated in Table 3. Extractions were then made, giving the results shown. These data again show that hematite does not fix phosphorus.

TABLE 3.—*Effect of temperature on the fixation of phosphorus by pure minerals, using 1-gram samples.**

Mineral	Heat treatment	Phosphorus remaining in solution		Phosphorus fixed		Phosphorus fixed insoluble in H_2SO_4 of pH 3.0	
		Mgms	%	Mgms	%	Mgms	%
Hematite	85° C for 8 days	17.4	100	None	——	None	——
Goethite	85° C for 8 days	0.75	4.3	16.65	95.7	16.6	95.4
Goethite	30° C for 28 days	3.1	17.8	14.3	82.2	11.9	68.4

*17.4 mgms of phosphorus added as H_3PO_4.

Fixation was greater in 8 days at 85°C than in 4 weeks at 30°. Digestion at the lower temperature was conducted primarily to determine the rate and nature of fixation at temperatures existing in soils. It is believed that fixation at the lower temperature would have gone more nearly to completion if sufficient time had been allowed. The atomic ratio of phosphorus to iron in these experiments was 1:2, which is a much narrower ratio than might be expected to exist in soils. Amounts of phosphorus in the ratio to iron of 1:4 and 1:1 were also added to samples and digested at the lower temperature.

After extraction with H_2SO_4 of pH 3.0, the residues were subjected to X-ray analysis. The X-ray patterns were the same for materials digested at both the higher and the lower temperatures, and these were all different from that of the original Goethite. These results show that when phosphorus is fixed by Goethite a crystalline phosphate of very low solubility is formed. The exact nature of this compound is not known. Preliminary investigations show that the phosphorus fixed by Goethite is at least as insoluble as that of dufrenite.

INFLUENCE OF HEATING GOETHITE AND BAUXITE ON THEIR FIXING POWER

The hydrated oxides of iron and aluminum on heating lose water, the Goethite becoming Fe_2O_3 and the bauxite Al_2O_3. It has been

shown that hematite does not fix phosphorus, therefore, the dehydration of Goethite should destroy its fixing power. Samples of Goethite and bauxite were heated in an electric muffle furnace for periods of 2 hours at temperatures ranging from 200° to 600° C and the loss of water determined. No attempt was made, however, to bring the samples to constant weight by re-heating at any given temperature. The heated samples were used in fixation studies as in the case of soils, phosphorus being supplied in a very dilute solution of H_3PO_4. Fixation in the case of Goethite decreased with each decrease in water content. On complete dehydration this substance did not fix phosphorus and gave an X-ray pattern identical with that of hematite.

Posnjak and Merwin (20) examined a large number of samples of hydrated iron oxide, including samples varying in water content from 10 to 15%. The critical dehydration temperature of each sample and also the critical indices for all crystall ne samples were determined. A characteristic dehydration curve with a single abrupt break, occurring at 140° to 220° C for the different samples, was found in all cases. The critical indices were approximately the same in all cases. These investigators concluded that no series of naturally occurring hydrated oxides of iron exists; that only the mono-hydrate ($Fe_2O_3.H_2O$) exists; that its water (10 1%) is water of crystallization; that water in excess of 10.1%, held in other so-called hydrated iron oxides is not water of crystallization but is held mechanically; and that the end-product of dehydration is hematite. They retain the term limonite, but restrict its application to amorphous ferric oxide mono-hydrate. Attempts to re-hydrate the dehydrated Goethite were unsuccessful. This work confirmed the earlier, but less comprehensive, work of Bohm (1) on the naturally occurring hydrated oxides of iron. However, Huettig (15) states that a series of hydrated oxides of iron has been prepared from Fe $(OH)_3$ under experimentally controlled conditions.

In the case of unheated bauxite, little of the fixed phosphorus was held after prolonged extraction in H_2SO_4 of pH 3.0. However, heating of the bauxite for 2 hours at 200°C resulted in a material increase in phosphorus fixation and drove out 5% of the water. On heating to 250°C for 2 hours, 20% of the water was driven off, but the capacity to retain phosphorus in the presence of H_2SO_4 of pH 3.0 was greater than when heated at either higher or lower temperatures. There are two hydrated oxides of aluminum, the mono-hydrate, diaspore ($Al_2O_3.H_2O$) containing 15% of water, and the tri-hydrate, Gibbsite ($Al_2O_3.3H_2O$), containing 34.6% of water. Since heating bauxite at low temperatures increases the fixation while heating at higher temperatures tends to reduce fixation below the maximum, and since maximum fixation occurs when the water content corresponds approximately to that of the mono-hydrate, it seems logical to assume that the tri-hydrate of aluminum oxide fixes phosphorus less firmly than the mono-hydrate. No pure samples of the mono- and tri-hydrates were available for study.

Samples of bauxite heated at 250°C for 2 hours were taken for fixation studies as in the case of Goethite. After fixation had gone

practically to completion, the solubility of the fixed phosphate was found to be very low. The residue, after extraction in H_2SO_4 of pH 3.0, was subjected to X-ray analysis, which showed that a crystalline phosphate was formed.

It should be stated that heating bauxite to redness did not entirely destroy its power to fix phosphorus. The amount fixed is least in the unheated bauxite and greatest in the partially dehydrated state. The reason why heating bauxite to redness does not stop fixation entirely is not known. It may be due to impurities commonly present.

INFLUENCE OF HEATING SOILS ON THEIR FIXING POWER

Samples of soils were heated at temperatures ranging from 185° to 260° C from 12 to 30 days. Samples were also heated for shorter periods of time at 400° to 700° C. The temperatures selected for prolonged heating were based on the results reported by Posnjak and Merwin (20). Prolonged heating at relatively low temperatures should stop fixation due to Goethite without materially increasing fixation due to bauxite.

Samples of the heated soils were used for fixation studies in the manner previously described. For checks, heated samples not treated with phosphate were also used. The effects of heating soils were greatly to increase the amount of readily soluble phosphorus due probably to liberation from organic matter and greatly to decrease the fixation of the phosphorus applied as mono-calcium phosphate. Extraction of phosphate was continued in each case until equilibrium was established, which was 4 hours in the case of the high temperature treatment and 8 hours in the case of the low temperature treatment. The results are given in Table 4.

These data show that heating the soils greatly decreases fixation The decrease in fixation at 185° may be attributed to the dehydration of Goethite. The failure in some cases to reduce fixation by heating at 260° for 30 days as much as by heating at 185° for a similar period may be due to the increased activity of bauxite at the higher temperature. Soils having considerable bauxite would be influenced in this way. Goethite should be completely dehydrated on heating at the higher temperature.

Fraps (10) found that heating reduced the fixation of phosphorus by certain Texas soils, while Lipman (17) found that heating increased fixation by certain California soils. On the basis of the data just given, it seems that these conflicting ideas may be due to differences in the proportion of Goethite and bauxite contained in the soils. Similarly, it appears from the data given in Table 4 that the Russellville soil contains little or no bauxite, while this substance appears to be, in part, responsible for fixation of phosphorus in the other soils. Bauxite seems to be especially important in the case of the Campbellsville and Greenville soils which retain some power to fix phosphorus after being heated to 700°C.

TABLE 4.—*Effect of heating soils on their fixing power.**

Source of soil	Percentage of phosphorus fixed							
	Un-heated soil	185° C		210° C, 13 days	260° C		400° C 24 hours	700° C 4 hours
		12 days	30 days		16 days	30 days		
Berea field	50	20	15	20	25	5	20	0
Campbellsville field	55	20	15	10	30	10	25	10
Russellville field	35	0	0	0	—	—	0	0
Greenville field	55	40	20	15	15	25	40	5
Fariston field	55	40	10	10	40	20	30	0
Mayfield field	50	20	10	10	30	25	0	0

*Fifty p.p.m. phosphorus added to 1-gram samples of soil as $CaH_4(PO_4)_2$.

The phosphorus soluble in H_2SO_4 of pH 3.0 in the heated soils ranged from 15 to 50% of the total. Marais (18) and others have shown that the solubility and availability of certain mineral phosphates may be increased by heating. The increases due to heating minerals, as shown by these investigators, do not, however, account for the great increase in solubility of the phosphorus in certain of the soils studied here. Peterson (19) has shown that heating soils results in a great increase in soluble phosphorus. He believed this to be due largely to oxidation of the organic matter. Stewart (22) has shown that a fairly constant carbon-phosphorus ratio exists for many soils.

OCCURRENCE OF HYDRATED OXIDES OF IRON AND ALUMINUM IN SOILS

Leith and Mead (16) and others state that the hydrated oxides of iron and aluminum occur in soils as products of the laterization process. On this basis it seems that lateritic soils should possess a high capacity to fix phosphorus in relatively insoluble forms. Preliminary work on a Cuban laterite showed this soil to have a very high capacity to fix phosphorus. Soils of intermediate nature between the laterites and podsols should also possess considerable capacity to fix phosphorus in relatively insoluble forms.

Gruner (14) has shown that ferric iron may be reduced on being leached with water which first passes through peat. This ferrous iron may form ferrous carbonate which Dana (2) states may form limonite on oxidation. In addition to the laterites, certain soils of the temperate zones, especially if subjected to reducing conditions, may contain appreciable amounts of the hydrated oxide of iron.

AVAILABILITY OF PHOSPHATES FIXED BY SOILS AND MINERALS

The phosphates formed on the union of phosphorus with Goethite and partially dehydrated bauxite are of very low solubility. Their availability to plants is also assumed to be very low. The subject, however, needs further investigation. Marais (18) made extensive studies with soil cultures on the availability of mineral phosphates. He found that dufrenite did not appreciably increase yields of buck-

wheat and sweet clover. Wavelite gave a slight increase in crop yields. The phosphates formed with Goethite and partially dehydrated bauxite have a solubility in H_2SO_4 of pH 3.0 comparable to that of dufrenite and wavelite, respectively.

Tidmore (23) has shown that plants will not grow normally in a nutrient solution containing as small an amount of phosphorus as that found in the displaced soil solution of certain soils which support satisfactory plant growth. It is not believed that any considerable amount of phosphorus can remain in the soil solution in the presence of high amounts of Goethite and bauxite. In the soils studied, a portion of the phosphorus fixed seems to be fixed in easily hydrolizable forms. This form of fixation appears to occur to an important extent in the case of the Russellville soil, but to a much less extent in the case of the Campbellsville, Greenville, and Fariston soils. Field observations made on the Greenville and Fariston soils point to the desirability of applying phosphates at least twice during the crop rotation period. The availability of the applied phosphates under field conditions, as reported by the writer (7), seem too low in certain cases to account for the crop yields obtained. It should be pointed out, however, that large applications of phosphates were made to these soils.

Gericke (12) has shown that plants may obtain sufficient phosphorus from a nutrient solution in the early period of their growth to carry them to maturity. Doubtless this explains, in part at least, the good growth of crops obtained when soluble phosphates are applied near planting time to soils of high fixing power.

Of the phosphates fixed by the soil, the calcium and magnesium phosphates are the most available, being readily soluble in carbonated water; the ferric and aluminum phosphates formed with the relatively soluble iron and aluminum compounds of the soil are of intermediate solubility, being at least in part readily hydrolizable, especially in neutral soils; while the phosphate formed with Goethite is of very low solubility. The phosphate formed with bauxite seems to be of intermediate solubility.

SUMMARY

The nature of phosphate fixation in soils was studied. Soils and certain pure minerals believed to be present in soils were treated with soluble phosphates and later examined for degree and nature of fixation. The soils fixed phosphorus in varying degrees in forms not easily soluble in H_2SO_4 of pH 3.0.

Goethite (limonite) fixed phosphorus in a form largely insoluble in H_2SO_4 of pH 3.0, while hematite did not. The phosphorus fixed by bauxite was of intermediate solubility. The dehydration of Goethite through heating produced hematite, thereby destroying its fixing power. The partial dehydration of bauxite increased its fixing power. Further dehydration reduced this capacity but did not entirely destroy it. The phosphates formed with Goethite and partially dehydrated bauxite were found on X-ray analysis to be crystalline.

Prolonged heating of six soils at 185° destroyed fixation in rel-

tively insoluble forms in one soil, practically destroyed it in two others, and greatly reduced it in the remaining three. This great reduction in fixation is believed to be due chiefly to the dehydration of Goethite. The failure of prolonged heating at 260°C to reduce fixation correspondingly in some soils is believed to be due to the increased activity of bauxite, brought about by heating.

The phosphorus fixed by soils as calcium or magnesium phosphates is readily soluble in weak solvents and thus quite available to plants; that which is fixed as ferric and aluminum phosphates by ferric and aluminum hydroxides, chlorides, or sulfates is at least in part easily hydrolizable and available to plants; while that which is fixed by Goethite (limonite) is very insoluble and only slowly available to plants. The amount of Goethite present in different soils is believed to vary greatly and to persist in soils when once formed, because of insufficient heat in soils to dehydrate it.

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PRELIMINARY STUDIES OF THE EXUDED PLANT SAP AND THE RELATION BETWEEN THE COMPOSITION OF THE SAP AND THE SOIL SOLUTION[1]

W. H. PIERRE and G. G. POHLMAN[2]

Although it has long been known that the cutting of plant stems often results in a bleeding or excretion of sap, very little is known regarding the inorganic composition of this exuded sap. The studies that have been reported have dealt mainly with the organic constituents of the sap or with the mechanism of exudation. Moreover, since vines are probably the most noted example of plants exhibiting this phenomenon, a majority of the studies have been conducted with the vine, *Vitus vinifera* L., while few studies have been reported with herbaceous plants. A probable reason for this is that until relatively recently there have been few satisfactory methods for determining small amounts of various inorganic constituents.

In recent years there has been considerable interest among investigators in plant nutrition regarding the composition and reaction of the expressed plant juice obtained from various plants and parts of plants, and some very interesting and valuable contributions have been made by this method of study. Probably its greatest value has been in the study of soil-plant relationships. The chief criticisms that may be raised against the method are that the juice obtained cannot be assumed to have the same composition as the original tissue fluids, and secondly, that the composition of the juice may vary considerably depending on the method of extraction. Newton, *et al* (19)[3] make the following statement in this connection: "When plant tissue is ground and the juice pressed out, the vacuolar sap and protoplasmic colloids, which are separate in the cell, become intimately mixed. Equilibria must be altered and probably hydrogen-ion concentration changed, with resulting changes in bound water and freezing point

[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director as Scientific Paper No. 114. Received for publication July 2, 1932.

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[3]Reference by number is to "Literature Cited," p. 159.

depression." Therefore, they point out the need of careful standardization of the extraction procedure, particularly with regard to the pressure used.

In view of these difficulties when working with expressed juice, it would seem that the exuded sap of plants might be more valuable in certain studies of plant-soil relationships than is the expressed sap, or, more correctly, the expressed plant juice.

Lowry and Tabor (18) in a recent note give three reasons why the exuded sap is to be preferred to the expressed juice, namely "the ease of securing sap by bleeding, its similarity to the displaced soil solution, and its favorable condition of analysis with a minimum of corrective treatments." While these investigators do not discuss or give any data on the latter two points, they state that a single corn plant will, under favorable conditions, bleed more than 500 cc of sap during a 3-day period.

So far as the writers are aware, the only plant nutrition investigation thus far reported in which studies have been made of some of the inorganic constituents of the exuded sap is that of Sabinin and Kolotora (25). These investigators determined the phosphorus, potassium, calcium, and nitrate nitrogen content of the sap obtained from corn plants grown in culture solutions of different pH values. They also studied the concentration of these elements found in the sap in relation to the concentration which was present in the culture solution

No studies, however, have been reported of the composition of the sap of plants grown in soils in relation to the composition of the displaced soil solution. In view of the above-mentioned considerations it seemed of interest to make some studies of the composition of the exuded sap.

The objectives of this investigation were as follows: (a) To determine the concentrations of various inorganic elements in the sap of corn and to study their relation to the concentration of the same elements in the soil solution. (b) To determine the effect of different degrees of soil acidity on the H-ion concentration of the plant sap. (c) To determine if differences in the sap of corn, sorghum, and Sudan grass can explain the difference in the ability of these plants to resist acid soil conditions. (d) To study the composition of successive portions of sap of corn.

METHODS USED

Corn, sorghum, and Sudan grass plants grown in the field during the summer of 1931 were used in these experiments. A description of the plants and the soils upon which they were grown will be given in the more detailed description of the experiments. The method described by Lowry and Tabor (18) was used in collecting the corn sap, each sample of sap coming from one stalk of corn. In the case of sorghum two nearby plants were cut at the same time and the sap from both collected in the same flask, whereas with Sudan grass three tubes were led into the same receiving flask from three adjacent plants. One cc of toluene was placed in each flask at the beginning of the collection, and the rubber stopper which was fitted into the

rubber tubing was placed as close as possible to the cut end of the stalk in order to reduce the amount of sap in the conducting system and thus reduce as much as possible any bacterial action which might take place before the sap reached the receiving flask.

In most cases and unless otherwise stated, the samples were collected during a 24-hour period. The sap, which was of a clear, watery appearance, was taken to the laboratory and the pH determination made immediately by the colorimetric method. Determinations of inorganic and organic phosphate were also made as soon as possible according to the blue colorimetric method described by Truog and Meyer (28). Calcium was precipitated as the oxalate in 15-cc centrifuge tubes at pH 4.5 to 5.0 by means of ammonium oxalate, and the determination carried out according to the micro method of Clark and Collip (6). Chlorine was determined volumetrically by means of silver nitrate, using potassium chromate as an indicator. Silica was determined by the colorimetric method of Dienert and Wandenbulcke (9). Nitrates were determined by the phenoldisulfonic acid method as described by Frear (10).

EXPERIMENTAL RESULTS

TOTAL SOLIDS IN PLANT SAP

It has been generally recognized that the sap obtained from plants by bleeding contains both organic and inorganic constituents. Barton-Wright (1), in his review of the recent advances made in plant physiology, makes the following statement: "The fluid that escapes in bleeding may be either practically pure water or may contain considerable quantities of organic matter. The sap of *Acer platanoides* contains 1.15 to 3.4 percent of cane sugar, while other plants such as the vine and potato yield practically pure water." It is evident from a review of the literature, however, that what is meant is that the sap from the potato and vine are relatively low in organic constituents.

TABLE 1.—*Solids in plant sap.*

Investigator	Plants	Dry matter expressed as p.p.m.		
		Combustible material	Ash	Total dry matter
Warmall (30)...	*Vitus vinifera* L. (vine)	1000	560	1,560
Priestley and Armstead (23)	*Vitus vinifera* L. (vine)	2060	660	2,720
Chibnall and Grover (5)........	*Clerodendron trichotomum**	1160	940	2,100
Ulbricht (29)	Potato	450	1,160	1,610
Bose (2)	Cucurbita	1550	1,750	3,300
Bose (2).........	Corn	—	1,500	—
Pierre and Pohlman	Corn†	2651	1,055	3,706

*Sap exuded from cut end of small branch sealed in a steel cylinder and subjected to a pressure of 20 atmospheres. Therefore, this sap is not strictly comparable to others.

†Average of sap from four plants.

In Table 1 are summarized the amounts of combustible material and of ash found in the sap of different plants as reported by various investigators (2, 5, 23, 29, 30). The amounts present in the sap of corn as found in the present study are also given. When it is considered that the plants and the condition under which these various samples were collected were very different, it is rather surprising not to find greater variations in total solids. The vine, however, appears to have a higher proportion of organic constituents in its sap than do most of the herbaceous plants studied. This is what might be expected since the latter, no doubt, have less storage of organic reserves in their roots. When it is considered that in combustion some of the inorganic substances may be lost, it is evident that a considerable part of the solids in the sap of these herbaceous plants is in the inorganic form.

CONCENTRATION OF VARIOUS INORGANIC ELEMENTS IN PLANT SAP AND ITS RELATION TO CONCENTRATION OF THESE ELEMENTS IN DISPLACED SOIL SOLUTION

In this experiment sap was obtained from nine corn plants selected from different fields or different sections of the same field. The corn stalks were cut at about 4:00 p. m. The next morning the first samples, marked 1A to 9A, were collected. A second series of samples was collected on the following morning after a period of 24 hours. These will be referred to as the B samples. Since it rained during the latter part of the first night the B samples were collected during a period of higher soil moisture content than the A samples. Several

TABLE 2.—*The specific resistance and H-ion concentration of the plant sap of corn and of the soil solution or soil extract.*

Plant No.	Stage of growth of corn plants	Amount of sap, cc		Specific resistance (25°C), ohms			H-ion concentration, pH		
		Sample A	Sample B	Sample A	Sample B	Soil solution	Sample A	Sample B	Soil extract
1	Tasseled	Lost	61	—	577	330	—	4.65	5.13
2	Ear formed	57	62	1,111	1,470	224	4.60	4.60	5.05
3	Tasseled	66	76	576	909	440	4.55	4.65	4.70
4	Before tasselling	58	45	665	666	644	4.65	4.65	4.78
5	Before tasselling	67	63	426	602	1,033	4.75	4.80	4.45
6	Before tasselling	69	35	618	930	262	4.60	4.65	6.53
7	Tasseled	—	55	844	1,109	324	4.60	4.60	4.70
8	Ear formed	67	70	655	837	304	4.60	4.50	5.88
9	Ear formed	56	51	635	689	262	4.55	4.30	6.53

days after collecting the sap, when the soil had dried sufficiently, samples of soil were removed from around each plant and the soil solution of each was immediately displaced by the method of Burd and Martin (4). Similar analyses were made of the soil solution as of the plant sap samples. The results of these analyses are given in Tables 2 to 4, inclusive.

The specific resistance of the samples of sap was, in general, quite high, as will be noted in Table 2. In all cases but one the soil solution had a lower specific resistance or a greater electrolyte content than did the plant sap. The H-ion concentration of the different sap samples was found to vary only slightly in spite of the fact that the pH of the soils varied from 4.45 to 6.53.

Table 3 gives the phosphorus and calcium data. The total phosphate concentration in the different samples of sap varied from 132 to 441 p.p.m. Of these amounts, over two-thirds, and in some cases nearly all, was in the inorganic form. The displaced soil solution, on the other hand, contained only very low concentrations of phosphate. This means that the sap contained 552 to 4,967 times as high a concentration of phosphate as did the displaced soil solution; or, in other words, that the "concentration factor" varied between these two limits. The concentration of calcium in the plant sap, however, was much lower than in the displaced soil solution, the concentration factor ranging from 0.086 to 0.621.

The results of the nitrate, chloride, and silica analyses are given in Table 4. It will be noted that the nitrate concentration in the plant sap varied from a trace to nearly 100 p.p.m., while the concentration of nitrates in the soil solution was in most cases lower. In three of the sap samples only a trace of nitrates was found. It is possible, however, that some loss of nitrates occurred in some of these samples of sap before the determinations of nitrates were made. In some later studies as high as 344 p.p.m. of nitrate nitrogen was found in the sap of corn plants grown in the greenhouse.

One of the most interesting results obtained was the high concentration of soluble silica found in the plant sap. It will be noted that the concentration of silica is even greater than that of phosphate. As with phosphorus, the concentration in the soil solution is very much lower than in the plant sap. On the other hand, it will be noted that chlorides are found in much lower concentrations in the plant sap than in the soil solution. Thus it would seem that calcium and chlorides are present in higher concentrations in the soil solution than in the sap of these plants, whereas phosphorus, silicon, and nitrate nitrogen in most cases are found in higher concentration in the plant sap than in the displaced soil solution. The significance of these results in relation to the problem of nutrient absorption and accumulation by plants will be considered in more detail in the latter part of this paper.

Since in this study the plants used were of different stages of maturity and since the sap of only one plant was obtained from each location, it is obviously not permissible to draw any conclusions regarding the correlation which might exist between the concentrations of any element in the soil solutions and in the corresponding sap samples. It is interesting to note, however, that with phosphorus there does seem to be some correlation between the concentration in the soil solution and in the plant sap. A better correlation is that between the phosphorus in the soil extract and in the plant sap. This is in general agreement with the results of an accompanying study (22) in which the phosphate concentration in the plant sap

TABLE 3.—*The phosphorus and calcium concentration of the cell sap of corn and of the displaced soil solution expressed as p.p.m.*

Plant No.	Phosphate						Calcium		
	In plant sap			In soil solution (inorganic)	Concentration factor	In soil extract (inorganic)	In plant sap	In soil solution	Concentration factor
	Inorganic	Organic	Total						
1*	190	82	272*	0 10	1,900	1.04	—	398	—
2	171	99	270	0.31	552	1.26	47	544	0.086
3	154	50	204	0.06	2,567	0.30	98	276	0.355
4	85	47	132	0.07	1,214	0.31	116	234	0.496
5	149	44	193	0.03	4,967	0.30	92	148	0.621
6	179	11	190	0.14	1,278	0.45	86	660	0.130
7	154	22	176	0.09	1,711	0.28	71	316	0.224
8	309	132	441	0.17	1,818	3.50	55	434	0.126
9	259	104	363	0.09	2,878	3.75	63	488	0.129

*B sample.

TABLE 4.—*The nitrate, silica, and chloride content of the plant sap of corn and of the displaced soil solution expressed as p.p.m.**

Plant No.	Nitrates		Silica			Chlorides		
	In plant sap	In soil solution	In plant sap	In soil solution	Concentration factor	In plant sap	In soil solution	Concentration factor
1	Trace	14	440	14	31.4	204	860	0.237
2	Trace	18	418	20	20.9	42	1,212	0.034
3	35	14	308	14	22.0	70	500	0.140
4	—†	—†	374	13	28.8	76	690	0.110
5	46	19	198	13	15.2	88	142	0.620
6	98	14	242	10	24.2	36	732	0.049
7	16	15	275	14	19.6	82	484	0.170
8	Trace	21	440	18	24.4	68	864	0.078
9	46	15	418	12	34.8	122	1,004	0.121
Ave.					24.6			0.173

*B samples were used for studies of NO_3, SiO_2, and Cl.
†No determination.

of corn was found to bear a relationship to the availability of phosphate compounds in the soil.

EFFECT OF SOIL ACIDITY ON COMPOSITION OF SAP OF PLANTS WHICH SHOW DIFFERENT DEGREES OF TOLERANCE TO SOIL ACIDITY

It has been recognized quite generally that corn is less injured by soil acidity than are sorghum and Sudan grass. It seemed of interest, therefore, to study the composition of the sap of these three plants when grown on soils of different degrees of acidity, especially with respect to calcium, phosphorus, and H-ion concentration.

Corn, sorghum, and Sudan grass were drilled in alternating rows 3½ feet apart in an area of Dekalb silt loam. This soil area which was originally very acid, was divided into three sections one of which received no lime, the second a moderate application, and the third a high application. Thus the three crops were each grown at approximately the following pH values: 4.6, 5.1, and 6.6. Good growth of all crops was obtained on the soils having the two higher pH values, but relatively poor growth of sorghum and Sudan grass was obtained on the most acid section. Stalks of each of the three species were cut for collection of sap on September 8. At this time the sorghum and Sudan grass were beginning to head, while the corn was tasselled. All plants were still in an active vegetative state of growth. The soil was moist as a result of recent rains and conditions were favorable for the collection of sap. The samples were collected during the same 24 hours in order that they might be comparable. Another group of samples was collected on September 10 and additional samples from the corn and sorghum on September 28. Samples of soil were removed from around the roots of each plant used in the study for determinations of H-ion concentration. Approximate yield data of

the three crops grown at the different reactions were obtained by harvesting a representative 10-foot section of each drilled row.

The results obtained are summarized briefly in Table 5. As was to be expected, the yields of all crops were highest at the least acid reaction, and the sorghum and Sudan grass were more injured than was corn at the most acid reaction. The greater injury of sorghum and Sudan grass, however, does not seem to be correlated with or explained by differences in the calcium, phosphorus, or H-ion concentration of the sap. It will be noted that the H-ion concentration of the sorghum sap was only slightly lower and the Sudan grass sap slightly higher than that of the corn sap. The calcium concentration in the sap of corn and sorghum was very similar, while that of Sudan grass was somewhat higher. On the other hand, phosphorus was found in slightly lower concentrations in the sorghum sap than in the corn and Sudan grass sap.

TABLE 5.—*The average calcium, phosphorus, and H-ion concentration of the cell sap of corn, sorghum, and Sudan grass grown at three different degrees of soil acidity.*

Crop	Acidity of soil, pH	Relative yield of crops	Number of plants sampled for sap	Composition of sap		
				H-ion concentration, pH	Ca, p.p.m.	PO_4, p.p.m.
	4.62	82	5	4.65	74	219
Corn	5.10	83	5	4.65	77	217
	6.57	100	5	4.70	79	201
	4.62	50	8	4.90	74	157
Sorghum	5.10	94	8	4.70	71	186
	6.57	100	8	4.85	72	186
	4.62	33	6	4.60	131	194
Sudan grass	5.10	90	6	4.55	101	180
	6.57	100	6	4.60	107	205

Moreover, if each plant species is considered separately, no correlation is noted between the H-ion, calcium, and phosphate concentration of the sap and the differences in plant growth as a result of soil acidity. For example, calcium is found in just as high concentrations in the sap of sorghum and Sudan grass plants which show injury from soil acidity as in that of similar plants grown on soils near neutrality. This indicates that the reason these plants make poor growth when grown on acid soils is not that they are unable to obtain calcium from the soil solution. Neither does it appear that Sudan grass is less able to absorb phosphorus from acid soils than is corn, for no significant differences were obtained between the phosphate concentration of the Sudan grass sap from plants grown on soils of different pH values. Sorghum seemed to absorb slightly less phosphorus when grown at pH 4.60 than at pH 5.10 and 6.60, but this difference may not be very significant when plant variations and the small number of plants used are considered.

Liming did not result in a significant decrease in the acidity of the sap of any of the three crops. These results are in accord with

those of Clevenger (7) with the plant juices of soybeans, cowpeas, and oats, and of Haas (12) with corn, although the latter found that the expressed juice of wheat, white mustard, and some of the clovers had a higher pH on limed than on unlimed soils.

An effort was made to determine the aluminum concentration of the samples of sap collected, since it seemed possible that sorghum and Sudan grass might absorb aluminum more readily and thus be injured more than corn when grown on acid soils containing soluble aluminum. It was found that, although 3.2 p.p.m. of aluminum were present in the displaced soil solution, the amounts of aluminum in the sap were so small that they could not be determined in 20-cc samples of sap, the amount which represented the maximum available for the study.

Some determinations were also made of the chloride and silica content of the sap of corn and sorghum plants grown at pH 4.6 and 6.6. The results obtained showed that the concentrations of chloride was not affected by differences in soil acidity, but that silica was found in greater concentration in the sap of plants grown at the least acid reaction.

While these data indicate that the H-ion, calcium, phosphorus, and chloride concentrations of the sap of corn are not affected by variations in soil reaction from 4.6 to 6.6, yet it is possible that if the soil were limed to much higher pH values some changes might have been obtained. Sabinin and Kolotora (25) found that with corn grown in nutrient solutions there is a tendency for a greater accumulation of cations in the sap at high pH values and of anions at low pH values.

COMPOSITION OF SUCCESSIVE SAMPLES OF EXUDED SAP

Since the results of Hofmeister (16) and of Lowry and Tabor (18) show that herbaceous plants may continue to exude sap for a considerable period after cutting, it seemed of interest to make a brief study of the composition of successive portions of sap collected. Therefore, three corn plants in the tasselling stage of growth were cut near the ground and properly connected with tubing for the collection of their sap. The first four samples from each plant were removed from the flasks after successive 24-hour periods, and the fifth set of samples was collected during a 48-hour period beginning with the fifth day. No further samples were collected, since those of the fifth set were turbid and were affected apparently by bacterial action or had undergone physiological changes. Determinations of H-ion concentration, specific resistance, inorganic and organic phosphorus, and calcium were made on all samples collected. The results are given in Table 6. It will be noted that at first about 30 cc of sap were obtained from each plant during a 24-period, but that after the second day the amounts of sap obtained gradually decreased.

The H-ion concentration of the sap of plant A gradually decreased as bleeding continued. With plants B and C, however, the first three samples collected were approximately the same in pH. The samples of the fifth set, which in all cases were slightly yellowish and turbid,

TABLE 6.—*The specific resistance and the H-ion, phosphorus, and calcium concentration of successive portions of the exuded sap of corn.*

Plant No.	Oven-dry weight of plant, grams	Successive portions by days	Amount of sap, cc	H-ion concentration, pH	Specific resistance (25°C), ohms	PO_4 concentration: Inorganic p.p.m.	PO_4 concentration: Organic p.p.m.	PO_4 concentration: Total, p.p.m.	Ca, p.p.m.
A	70.2	1	32	4.45	793	98	86	184	106
		2	29	4.75	1,164	155	59	214	73
		3	20	5.00	1,395	114	45	159	64
		4	12	5.15	1,376	101	57	158	—
		5 and 6	11	6.00	1,211	110	41	151	82
B	113.8	1	19	4.70	1,173	104	124	228	92
		2	31	4.65	958	154	13	167	98
		3	25	4.65	790	198	5	203	100
		4	17	4.85	589	198	41	239	111
		5 and 6	22	6.40	397	223	42	275	126
C	93.0	1	19	4.70	887	140	85	225	110
		2	43	4.90	814	169	62	231	63
		3	39	4.80	661	178	50	228	64
		4	26	5.15	544	183	45	228	76
		5 and 6	70	5.80	520	180	26	206	68

had a much lower H-ion concentration. These results seem to be in accord with the observations made by Crozier (8) that the acidity of the vacuole content of plant cells tends to decrease as natural death approaches.

As with H-ion concentration, the changes in the specific resistance of successive portions of sap from plant A are quite different than from plants B and C. With the latter plants, the sap gets more concentrated in electrolytes as bleeding proceeds, while with plant A there is a higher concentration of electrolytes in the first than in succeeding samples. Part of this difference in the specific resistance of successive samples collected from plant A and from plants B and C probably can be explained by the inorganic phosphate content. It will be noted that the inorganic phosphate concentration of succeeding samples from plant A remains about the same, whereas in the sap obtained from plants B and C it gradually increases. In contrast to the concentration of inorganic phosphate, the organic phosphate tends to decrease as bleeding proceeds. The result of these opposite tendencies is to keep the total phosphate of successive samples about the same, although it will be noted that there are some variations.

The decrease in organic and the increase in inorganic phosphorus as bleeding proceeds is of interest. Whether this is due to a gradual change of organic phosphate to the inorganic form or whether it is due to the fact that organic phosphorus is no longer being formed while absorption of inorganic phosphate from the soil solution continues, cannot be determined from this experiment.

It will be noted from the data in Table 6 that there is no consistent change in the calcium concentration of successive portions of the sap. The silica and chloride concentrations of the first three samples of sap from plant B were also determined. Silica was found to remain very constant, whereas the chlorides increased considerably as bleeding proceeded. Successive samples of sap from other plants showed similar results. It appears, therefore, that the increased chlorine content of the successive portions may partly account for the decreased specific resistance as bleeding continues.

It also seemed of interest to find out if there was any diurnal variation in the composition of the exuded sap. Two corn plants were cut at 10 o'clock in the morning and two samples of sap were removed from each plant every day for a period of 3 days. The day samples were collected between 10:00 a.m. and 5:00 p.m., while the night samples were collected between 5:00 p.m. and 10:00 a.m. the next morning. The results of this study are given in Table 7. In the first place it will be noted that the phosphate concentration of the sap is higher during the day than during the night. The H-ion concentration, however, is higher at night. The latter observation is in accord with results obtained by Clevenger (7), by Ingalls and Shive (17), and by others who worked with the expressed plant juices. The latter investigators found that the diurnal changes in H-ion concentration which they obtained were apparently governed by light intensities, for plants kept in the dark during a 24-hour period showed very little variation in the pH of their juices.

TABLE 7.—*Showing variations in the cell sap of corn collected at different periods of the day.*

Plant No.	Successive days	Sap samples collected between 10 a.m. and 5 p.m.				Sap samples collected between 5 p.m. and 10 a.m.			
		Rate of flow in cc per hour	pH	Total PO_4, p.p.m.	Ca, p.p.m.	Rate of flow in cc per hour	pH	Total PO_4, p.p.m.	Ca, p.p.m.
14	1	1.6	4.80	250	104	3.4	4.45	175	92
	2	3.1	4.80	258	66	2.1	4.60	179	62
	3	1.5	4.85	235	62	1.2	4.65	170	62
17	1	2.1	4.80	245	68	5.1	4.40	211	76
	2	3.9	4.70	244	66	3.5	4.40	203	66
	3	1.8	4.80	230	—	2.6	4.45	192	76

In the present experiment, however, it seems difficult to explain the diurnal variation in pH on the basis of light intensities, since only a short portion of the stem was exposed above the ground. It is more probable that temperature changes between night and day were responsible for the differences noted. In this connection Hoagland, *et al.* (15) found that the absorption of elements by *Nitella* has a high temperature coefficient.

These experiments indicate, therefore, that if quantitative comparable results are desired it may be essential to collect the sap of different plants during the same periods of the day if not during the same day. Moreover, for certain types of studies some consideration should, no doubt, be given to the stage of development of the plant and to its metabolic condition.

GENERAL DISCUSSION

The results obtained in this investigation are of interest in relation to the absorption and accumulation of inorganic elements by plants. It was shown that the concentration of the various elements in the soil solution is entirely different than in the plant sap of corn grown on the soils. The most striking illustration of this was the phosphorus content. While less than 0.4 p.p.m. of PO_4 was found in the displaced solutions of the soils upon which the plants were growing, over 300 p.p.m. of inorganic phosphate were found in solution in one of the samples of sap obtained. Even though it is assumed that the plants obtain their phosphorus from a very thin film around the soil particle which may be more concentrated in phosphorus than the displaced soil solution, the concentration factor would still be very high, for in some experiments with corn and with lettuce grown in complete nutrient solution with 1 p.p.m. PO_4, it was found that the sap contained as high as 400 p.p.m. PO_4. Moreover, as Parker's (21) work indicates, corn plants can make optimum growth with 0.5 p.p.m. PO_4 in solution.

This high concentration factor with phosphorus and also those with silica and nitrates mean that there is a decided concentration gradient

between the soil solution bathing the root hairs and the plant sap moving upward into the lower part of the stem. The results indicate that absorption at the root surface may take place from a solution of low concentration to one of a much higher concentration or that movement of certain inorganic elements in the root may take place from cells of low to cells of high concentration.

This is in accordance with the results obtained by Hoagland and his co-workers (13, 14) in their comprehensive studies regarding the absorption and accumulation of various elements in the cell sap of the fresh water alga, *Nitella clovata*. These investigators found that the total electrolyte content in the sap of *Nitella* was approximately 25 times as great as that of the water in which the plants were living, and that each of the principal cations and anions was found in much higher concentrations than in the culture medium. In the present study some elements, such as calcium and chlorine, were found in considerably lower concentrations in the cell sap of corn, sorghum, and Sudan grass than in the soil solution surrounding the root hairs. It is, of course, probable that if the soil solution had been very dilute higher concentrations of these elements might have been found in the plant sap than in the soil solution.

Osterhout (20) studied the relation between the concentration of various elements in the cell sap of the marine alga *Valonia macrophysa* and that of the same elements in the sea water surrounding the cells and found that sodium, magnesium, and sulfate were present in lower concentrations in the sap than in the sea water. Potassium, on the other hand, was found in much higher concentrations in the cell sap.

The similarity of the results obtained from the study of the cell sap of *Nitella* and *Valonia* and the sap obtained from higher plants by bleeding indicates that the mechanism of absorption and accumulation is probably of the same nature in both types of plants. This mechanism, as Hoagland concluded, is apparently not one of simple permeability or osmosis, but one which is associated with the metabolic activities of the living cell.

Hoagland found no evidence in his studies that the accumulation of bromine by *Nitella* cells could be explained by the formation of organic combinations in the sap and concluded that nearly all the inorganic elements present in the cell sap of *Nitella* exist in the ionic state. In the present study it is interesting to note that most of the phosphorus was presumably in the inorganic form. It is possible, of course, that the phosphate in the plant sap is in the form of slightly dissociated organic compounds and that these give the same reaction or test with reagents as the inorganic phosphate found in the soil solution. If that is the case, what appears as an accumulation of ions against a concentration gradient may be more apparent than real since the phosphate and other ions in the cell would be in a different chemical combination than those in the soil solution. Thus, the absorption and accumulation of the various elements in the plant cells might be explained on the basis of the Donnan equilibrium.

A simple Donnan equilibrium conception, however, was found inadequate by Briggs and Petrie (3) to explain the absorption of ions by carrot tissues placed in various salt solutions. They pointed out

that plant tissues must be looked upon as a polyphase system, and they suggested that the equilibrium between the internal phases and the solution might be explained by assuming that one internal phase contains indiffusible anions and another indiffusible cations.

Tiedjens (26) offers a somewhat similar but more comprehensive theory for the absorption of ions by plants and presents some interesting data in support of it. Thus, he found that in tomato tissue approximately one to three times as many nitrate ions were chemically combined with the protoplast (recovered by electrodialysis) than were free (recovered by aqueous extraction), and that the concentration of nitrate ions in the tissue was much higher than in the nutrient solution. He concludes that nitrate ions, for example, are combined with the proteins and soluble ampholytes in the cell and that the amount of absorption and of ions combined with ampholytes is dependent on the isoelectric point of the ampholytes as well as the pH of the cell sap and of the nutrient medium.

This theory is of particular interest and probably offers the best explanation for the "concentration factors" obtained in this study, although as Tiedjens states the mechanism suggested is probably more complex than is thus indicated.

The H-ion concentration of the sap of corn obtained in these experiments ranged around pH 4.65. It is interesting to note that the pH values of the expressed plant juice of corn reported by various investigators are considerably higher. The pH values of the expressed juice of corn reported by Haas (12) were 5.18 and 5.48. Gustafson (11) obtained a pH of about 5.6 for the expressed juice from the base of the stem of corn, while Truog and Meacham (27) obtained a pH value of about 5.21 to 5.31. The reason for these higher pH values with the expressed plant juice than with the exuded sap probably lies in the fact that in expressing the plant juice, tissues of various pH values are crushed and the resultant pH is not that of the unaltered sap or of any one tissue. On the other hand, the sap obtained by bleeding probably gives the pH value of the unaltered sap that moves upward in the stem. In this connection it is interesting to note that Rogers and Shive (24) have recently found that the xylem parenchyma tissue of corn had a pH of 4.6 to 4.8; the xylem vessels, 4.4 to 4.0; while the phloem had a pH of 6.2 to 5.8 and the cortex, 6.0 to 5.6. It seems very significant that the xylem tissues through which the upward flow of sap is rather generally conceded to take place have pH values closely approximating the pH of the corn sap obtained in these studies. On the other hand, it is obvious that in expressing the plant juice, the cells of high pH values, such as those of the phloem and cortex, will probably tend to give to the expressed juice a pH which is probably about the average for the various tissues and which is not that of the unaltered sap which moves upward into the plant.

It would seem as a result of these preliminary studies that the use of the cell sap obtained by bleeding offers a means of studying various problems relating to the absorption of various elements from the soil and their accumulation in the plant. For some types of investigation at least it is to be preferred to the expressed plant juice.

SUMMARY

Samples of the sap of corn, sorghum, and Sudan grass were obtained by cutting the stalk of plants near the surface of the ground and collecting the sap which exuded from the stump ends. Determinations of pH, specific resistance, and of phosphorus, calcium, nitrate nitrogen, silica, and chlorides were made on a number of the samples of sap obtained. Studies were made of the relation between the concentration of various elements in the plant sap and in the soil solution obtained from the soils upon which the plants were growing. Other experiments included studies of the composition of the plant sap of corn, sorghum, and Sudan grass as affected by three different degrees of soil acidity and studies of the composition of sap samples collected on successive days. The main results may be summarized as follows:

1. The sap of corn was found to contain an average of about 3,700 p.p.m. total solids of which approximately one-third was in the inorganic form.
2. The total electrolyte content of the sap as measured by conductivity determinations was found to be less in nearly all cases than that of the displaced soil solution.
3. The total phosphorus content of the sap of corn, sorghum, and Sudan grass was found to range between about 150 and 450 p.p.m. PO_4. Of this concentration generally over two-thirds and in some cases all were found to be in the inorganic form.
4. The concentration of silica in the plant sap was found to average about 250 p.p.m. of calcium, about 80 p.p.m. and of chlorides about 90 p.p.m., while nitrates were found to vary from a trace to 344 p.p.m.
5. Phosphorus and silica were found in much higher concentrations in the plant sap than in the displaced soil solution, "the concentration factor" for the former ranging from 552 to 4,967 and for the latter from 15.2 to 34.8. On the other hand, chlorides and calcium were found in considerably lower concentrations in the plant sap than in the soil solution. Nitrates were higher in some cases and lower in others in the plant sap than in the displaced soil solution
6. The data indicate that there may be a correlation between the concentration of phosphorus in the plant sap and in the soil solution and soil extract.
7. The pH values of the sap of corn, sorghum, and Sudan grass were found to be about the same, varying from about 4.40 to 4.80. Differences in soil acidity from pH 4.60 to 6.60 were not found to affect the acidity of the sap of any of the three species.
8. The relatively poorer growth of sorghum and Sudan grass than of corn on acid soils could not be explained on the basis of the inability of the former plants to accumulate calcium or phosphate in their saps when grown in acid soils.
9. The H-ion concentration of the soil was not found to affect the concentration of calcium, phosphorus, and chloride in the plant sap within a range of pH 4.60 to 6.60. With increased pH values of the soil a slightly greater concentration of silica was found in the plant sap.

10. Samples of sap from the same plants collected on successive days were found to remain quite constant in total phosphorus for a period of 4 days. The inorganic phosphate, however, was found to increase as bleeding proceeded, while the organic phosphate tended to decrease. Chlorides were found to increase in the sap as bleeding continued, but calcium and silica were not found to show any consistent variations.

The significance of these data in relation to the absorption and accumulation of inorganic elements in the plant sap is briefly discussed. It is also pointed out that studies of the plant sap obtained by bleeding may be found useful in various studies of soil-plant relationships.

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THE PHOSPHORUS CONCENTRATION OF THE EXUDED SAP OF CORN AS A MEASURE OF THE AVAILABLE PHOSPHORUS IN THE SOIL[1]

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Many methods have been proposed to measure the supply of soil phosphorus available to plants. Some of these have given satisfactory results on certain soils, but none has been found to be applicable to all soils. Recently a method based on the phosphorus content of the expressed juice of certain plants has been suggested as a possible means of determining the adequacy of the phosphorus supply to the plant (2, 8).[3]

In 1926, Gilbert (1) found a relationship between the phosphorus concentration in the expressed juice of corn and turnips and the amounts of phosphate fertilizer used. He suggested the use of expressed juice as a means of studying the nutrient supply inasmuch as it shows not only the amount of each element which gains entrance into the plant, but also the amount which may be used under favorable conditions of metabolism.

[1]Contribution from the Department of Agronomy and Genetics, West Virginia Agricultural Experiment Station, Mrogantown, W. Va. Published with the approval of the Director as Scientific Paper No. 115. Received for publication July 2, 1932.
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[3]Reference by number is to "Literature Cited," p. 170.

In the same year, McCool (5) noted striking differences in the phosphorus content of the expressed juice of several crops when grown on different soils, and suggested that, "it may be that a phosphorus deficiency in the soil may be detected by cell sap studies of crops grown on it."

Later, Gilbert, McLean, and Adams (3) found that the concentration of any one element was influenced by any other factor which would limit the growth of the plant. They also showed that, in general, the concentration of PO_4 in the expressed juice decreased as the season progressed. In 1927, Gilbert and Hardin (2) established a tentative critical concentration of 20 p.p.m. for the PO_4 content of the juice of the roots of turnips and carrots. They also studied the phosphate content of corn and cabbage tissues. The juice expressed from the corn stalk 1 foot above the upper node was found to contain from 26.8 to 38.4 p.p.m. of PO_4. The expressed juice from the lower leaves of cabbage was very low in phosphorus, containing only 0.86 to 5.20 p.p.m. PO_4.

McCool and Weldon (6), as a result of more extensive field and greenhouse studies, found that, in general, the application of fertilizers increased the content of the applied elements in the expressed juice. They found a higher concentration of nutrients in the leaves than in the stems of plants. The amounts of phosphorus found varied widely in different plants and no attempt was made to give optimum or critical concentrations for any element. Later, they (7) reported variations in the phosphorus content depending on the age of the plant, the amount increasing as the plant approached maturity.

Pettinger (8) studied the expressed juice of corn and suggested tentatively three division ranges which he considered would show very deficient, moderately deficient, and ample concentrations of nitrate nitrogen, phosphoric acid, and potash. The values given for P_2O_5 were as follows: Very deficient, less than 100 p.p.m.; moderately deficient, 100 to 200 p.p.m.; ample, more than 200 p.p.m.

Recently, Lowry and Tabor (4) suggested the use of the exuded sap rather than the expressed plant juice in studies of plant-soil relationships. The exuded sap had formerly been used by Sabinin and Kolotora (10) in studies of the absorption of phosphorus, potassium, and calcium by corn grown in culture solutions.

In some preliminary studies, the writers (9) determined the concentration of phosphorus, as well as of other elements, in the exuded sap of corn, sorghum, and Sudan grass, and found that the concentration of phosphorus was similar to that found by Pettinger (8) in the expressed plant juice. Moreover, some relation was noted between the phosphorus in the sap and that found in the soil solution and soil extract. In view of these considerations, it seemed desirable to study the possibility of using the exuded sap of plants as a means of determining the phosphate availability in soils. Tests were therefore made of corn sap to determine (a) the relationship between the phosphate content of the plant sap and the response of corn plants to phosphorus fertilizers, (b) the relationship between the phosphate

content of the sap and the phosphorus found available in the soil by other methods, and (c) the influence of age of plant on the phosphate concentration of the plant sap.

EXPERIMENTAL

The methods used in collecting and analyzing the sap have been described by the writers in another publication (9). The studies reported here were made from plants grown under greenhouse conditions and can only be considered to be preliminary.

The first samples were collected from corn grown in 2-gallon pots in the greenhouse. Monongahela fine sandy loam soil was used and the plants were grown from July 15 to October 6, at which time vegetative growth had practically ceased. The soil treatments, yield, phosphate concentration of the sap, and water-soluble phosphate content of the soil are given in Table 1.

TABLE 1.—*The influence of heavy fertilization with superphosphate on the PO_4 concentration of the soil extract and of the plant sap of corn.*

Phosphate fertilization in pounds per acre of 20% superphosphate	Pot No.	Dry weight of corn (3 plants per pot, ave. 2 pots,) 5 grams	P.p.m. of PO_4 in plant sap, Individual, Inorganic	P.p.m. of PO_4 in plant sap, Individual, Total	P.p.m. of PO_4 in plant sap, Average, Inorganic	P.p.m. of PO_4 in plant sap, Average, Total	P.p.m. of PO_4 in soil extract, Individual	P.p.m. of PO_4 in soil extract, Average
None	1		70	118			0.33	
None	1		73	129			0.30	
None	2	15.9	96	141	80	129	0.26	0.29
1,500	14		204	237			1.30	
1,500	14	27.3	178	198	191	218	1.40	1.35
3,000	17		209	242			4.00	
3,000	17		237	253			3.63	
3,000	18		226	237			3.75	
3,000	18	33 2	254	253	232	246	3.63	3.75
6,000	22		314	363			8.25	
6,000	23		314	369			8.28	
6,000	23	35.3	314	374	314	369	8.50	8.34

An examination of this table shows some rather striking correlations. First, it may be noted that the yield of corn increased with each additional amount of phosphate fertilizer added. This is surprising in view of the heavy applications made and the amounts of phosphate in the soil extract. The amounts in all of the fertilized soils are much higher than are normally present in fertile field soils. However, the plants were apparently not able to secure enough phosphorus for best growth until the water-soluble phosphate content of the soil exceeded 1.35 p.p.m. The amounts of phosphate in the plant sap are also of interest. The corn was apparently not sufficiently supplied with phosphorus in the untreated soils, although the sap contained 80 p.p.m. inorganic PO_4. The addition of phosphate fertilizer increased the content of phosphate in the sap, the greatest total increase being brought about by the 6,000 pounds per acre application of superphosphate.

The second group of tests was made on the sap of corn grown on nine different soils in the greenhouse. Seven of these soils had been used in a greenhouse study of phosphate response of alfalfa and the other two were obtained directly from the field. The soils used were as follows:

Soil No.	Soil Type
503	Brooke silt loam
504	Dekalb shale loam
506	Holston silt loam
507	Westmoreland silt loam
508	Dekalb loam
509	Upshur silty clay loam
534	Hagerstown silt loam
597	Dekalb silt loam
598	Dekalb silt loam

These soils had been previously limed to about pH 6.5. The fertilizer treatments are given in Table 2. The fertilizers were mixed well with the soil and the corn was planted on September 15. After the corn was well above the ground the stand was thinned to six plants per pot. During the growing period the number of plants was reduced to three as the result of cutting the plants for the collection of sap.

TABLE 2.—*Fertilizer treatment of soils in greenhouse.*

Pot No.	Treatment No.	Previous PO_4 fertilizer in pounds per acre	PO_4 fertilizer for corn in pounds per acre	KCl in pounds per acre
9 10	1a 1b	None	None	100
11 12	2a 2b	100 lbs. P_2O_5 in $CaH_4(PO_4)_2$ applied twice in last 2 years	None	100
13 14	3a 3b	100 lbs. P_2O_5 in $CaH_4(PO_4)_2$ applied twice in last 2 years	100 lbs. P_2O_5 in superphosphate	—
15 16	4a 4b	100 lbs. P_2O_5 in $CaH_4(PO_4)_2$ 1st year; 400 lbs. in 2d year	None	100
1 2	5a 5b	Heavy fertilization in field	None	100
3 4	6a 6b	Heavy fertilization in field	100 lbs. P_2O_5 in superphosphate	100

The weights of corn harvested during the growing period and at the time of final harvest are given in Table 3. The final harvest was made between December 30 and January 4, at which time the plants had about ceased vegetative growth. Inasmuch as little grain was produced the total weight of tops is given in all cases.

The average relative yield, based on the yields from the untreated soils as 100, is also given in the table. It is readily evident from this table that the addition of phosphorus fertilizers increased markedly the yield of corn in all of the soils except those two which had been heavily fertilized in the field (Nos. 597 and 598). Soils 504, 509, and 534 showed the lowest yields in the untreated and the highest percentage increase in yield. In addition to these, two other soils, Nos.

TABLE 3.—*Yield of corn on soil fertilized with different amounts of superphosphate fertilizer.*

Soil No.	Treatment No.	Dry weight in grams of 3 plants harvested before Nov. 25			Dry weight in grams of 3 plants at final harvest			Average relative yield*
		A	B	Ave.	A	B	Ave.	
503	1	5.9	5.6	5.8	18.2	22.2	20.2	100
	2	6.0	10.4	8.2	27.0	26.7	26.9	136
	3	8.5	8.1	8.3	37.2	28.6	32.9	159
	4	11.8	9.4	10.6	41.1	39.8	40.5	198
504†	1	1.4	4.1	2.8	17.8	12.8	15.3	100
	2	6.2	4.7	5.5	45.1	32.3	38.7	244
	3	9.0	8.8	8.9	57.7	50.3	54.0	348
	4	10.2	9.9	10.1	41.3	56.5	48.9	326
506	1	5.5	9.7	7.6	25.8	28.2	27.0	100
	2	8.1	7.3	7.7	39.9	34.1	37.0	129
	3	12.4	14.9	13.7	51.6	50.1	50.9	187
	4	12.6	13.0	12.8	50.7	43.7	47.2	173
507	1	4.1	5.0	4.6	14.2	13.7	14.0	100
	2	5.4	7.2	6.3	23.1	24.3	23.7	160
	3	11.8	10.7	11.3	35.0	22.8	28.9	215
	4	10.3	10.9	10.6	32.1	32.2	32.2	229
508†	1	4.7	4.8	4.8	14.6	18.0	16.3	100
	2	5.6	4.6	5.1	17.9	25.3	21.6	126
	3	8.8	11.3	10.1	45.1	35.9	40.5	240
	4	7.0	8.6	7.8	41.8	47.5	44.7	248
509	1	4.7	2.8	3.8	11.4	12.9	12.2	100
	2	9.9	8.3	9.1	29.0	29.8	29.4	240
	3	10.8	11.9	11.4	44.7	39.5	42.1	334
	4	15.3	11.4	13.4	71.5	51.3	61.4	467
534	1	1.8	2.6	2.2	6.3	9.3	7.8	100
	2	3.9	7.7	5.8	12.2	15.6	13.9	197
	3	7.7	8.1	7.9	30.2	24.3	27.3	352
597‡	5	10.0	6.2	8.1	10.1	10.1	10.1	100
	6	8.9	9.1	9.0	8.3	9.7	9.0	99
598	5	9.5	17.7	13.6	47.2	51.7	49.5	100
	6	15.1	24.2	19.7	53.7	43.4	48.6	108

*Based on untreated pots in each series as 100.
†Weight of two plants only in harvest before Nov. 25.
‡Weight of one plant at final harvest.

507 and 508, showed over 200% increase as a result of the higher phosphate applications. The other soils, Nos. 503 and 506, showed higher yields in the untreated soils than any of the other soils which showed response to phosphorus and also the lowest percentage increase due to fertilization.

Table 4 gives the phosphate concentration of the plant sap of the corn plants harvested at four different times during the growing period. Sap was collected from all of the treatments at the second

TABLE 4.—*Phosphate concentration of the plant sap of corn grown in the greenhouse in soils showing different responses to phosphate fertilization.*

Soil No.	Treatment No.	P.p.m. of inorganic PO_4 in cell sap					Average for treatment, p.p.m.
		Oct. 15	Nov. 3–5	Nov. 17–18	Dec. 26	Average	
503	1a		209	313		261	
	1b		75	276	388	246	254
	3a		229	210	362	267	
	3b		223	284		254	261
504	1a	141	193		323	219	
	1b	137	206		410	251	235
	3a	255	264		421	313	
	3b	198	230		336	255	284
506	1a		404	300	426	377	
	1b		264	253	602	373	375
	3a		198	264	483	315	
	3b		272	223	406	300	308
507	1a		137		268	203	
	1b		196		200	198	201
	3a		91		149	120	
	3b		386		473	430	275
508	1a	164	149		268	194	
	1b	176	78		279	178	186
	3a	324	195		494	338	
	3b	373	220		357	317	328
509	1a		101	104	273	159	
	1b		187	155	172	171	165
	3a		223	317	342	294	
	3b		193	239	437	290	292
534	1a			154	352	253	
	1b		183		410	297	275
	3a		310	458	577	448	
	3b		318	272	571	387	418
597	5a		305	334		320	
	5b		310	259		285	303
	6a		347	392		370	
	6b		330	313		322	346
598	5a	80	206		415	234	
	5b	95	346		461	301	268
	6a	94	173		383	217	
	6b	62	346		383	264	241

sampling. The analysis of the sap from corn on soils having treatments 2 and 4 are not included in the table. In general, however, they showed a gradual increase in phosphate content as the rate of fertilizer application was increased. Examination of the data shows that at the first cutting there was a good correlation between the response to phosphate and the increase in PO_4 in the sap as a result of phosphorus fertilization. The addition of phosphate increased appreciably the amounts of phosphorus in the sap in soils 504 and 508, but there was no increase in the phosphate content in the sap of corn on soil 598 due to the addition of phosphorus. No explanation can be offered for the small amounts found in the sap from the corn on soil 598 as this soil was apparently well supplied with phosphorus and the corn was making vigorous growth.

At the second sampling there is also a good correlation between the average phosphorus concentration of the sap and phosphate response. In soils 503, 508, 509, 534, and 597 there was in all samples an increase in phosphate content of the sap as a result of phosphate fertilization. Soils 504 and 507 also showed, on the average, higher phosphate content in the sap of the fertilized corn than in the untreated corn. Of the two soils which did not show such an increase, soil 598 did not respond to phosphate fertilization and soil 506 gave the best growth among the untreated soils of any of the soils responding to phosphorus. Soils 509 and 534 also showed increases in phosphate content of the third cutting in all of the samples which had been fertilized. Soil 597, which showed no increase in yield, and soils 503 and 506, which showed the least response to phosphorus fertilization, did not show any increase in phosphate content of the sap due to the addition of superphosphate to the soil. At the final cutting the sap from corn on soils 508, 509, and 534 again showed increased phosphate content in both of the samples as a result of fertilization, and samples from soils 504 and 507 showed, on the average, higher phosphate content, whereas samples from soils 503, 506, and 598 showed no increase as a result of fertilization with phosphorus. Rather, in these last three soils, there was a slight decrease in phosphate content in the sap from corn grown on the fertilized soils.

At each time of sampling it will be noted that the sap collected from corn on soils 508, 509, and 534 showed higher phosphate content as a result of phosphate fertilization, and soil 504 showed, on the average, a higher content of PO_4 in the sap of the plants grown on the fertilized soils. These soils also showed the greatest response in plant growth to the addition of superphosphate. It should be noted, however, that there is considerable variation in the PO_4 content of the sap collected from corn grown in duplicate pots. This is probably due largely to plant variation and possibly to some uncontrolled errors in the experiment. If more plants had been available for this study it seems probable that the average values thus obtained would have been even more significant.

In general, the phosphate content in the sap increased as the plants approached maturity. This is contrary to the results of Sabinin and Kolotora (10) who found that there was a decrease in the phosphate content of corn plants as the plants became older. The results

of these investigators, however, are not strictly comparable inasmuch as they grew plants in culture solutions which contained large amounts of PO_4. Gilbert, McLean, and Adams (3) also found a decrease in the PO_4 content of the juice from the upper part of the stem of corn as the season progressed. This may partly be accounted for by the part of the plant used and by the method of analysis. The results of McCool and Weldon (6) and of Pettinger (8) with the expressed juice of plants grown in the field showed that there was more phosphorus in the juice as the age of the plants increased. It might be expected that as plants become older they would use less of the phosphorus absorbed. Thus there would be a tendency for the accumulation of inorganic phosphorus in the plant juice.

TABLE 5.—*Available phosphorus as PO_4 in soils by the Truog method.*

Soil No.	Treatment No.	P.p.m. of PO_4		
		A	B	Average
503	1	47.5	57.5	52.5
	2	90.0	85.0	87.5
	3	92.5	100.0	96.3
	4	152.5	145.0	148.8
504	1	27.5	28.3	27.8
	2	31.6	28.3	30.0
	3	55.0	50.0	52.5
	4	75.0	87.5	82.8
506	1	41.6	44.7	43.1
	2	77.5	75.0	76.3
	3	92.5	95.0	93.8
	4	240.0	260.0	250.0
507	1	42.6	46.7	44.7
	2	87.5	90.0	88.8
	3	80.0	70.0	85.0
	4	150.0	190.0	170.0
508	1	25.0	21.8	23.4
	2	58.3	53.3	55.8
	3	60.0	65.0	62.5
	4	205.0	190.0	197.5
509	1	36.4	32.1	34.3
	2	60.0	52.5	56.3
	3	75.0	67.5	71.3
	4	115.0	120.0	117.5
534	1	29.1	32.3	30.7
	2	40.0	37.5	38.8
	3	55.0	60.0	57.5
597	5	80.0	100.0	90.0
	6	105.0	115.0	110.0
598	5	165.0	170.0	167.5
	6	240.0	255.0	247.5

Another possible explanation of the increase shown in the greenhouse may lie in the fact that during the latter part of the growing season the plants were not obtaining enough light for their maximum growth. This, then, would become the chief limiting factor and there might be a tendency for the accumulation of nutrients in the sap. This tendency has been noted by Pettinger, who found higher concentrations during the 1928 growing season when conditions were not as favorable for growth. McCool and Weldon (6) and Gilbert and his co-workers (3) also noted that if any one element was lacking, there was a tendency for the accumulation of other elements in the expressed juice.

The available phosphorus as determined by the Truog method is shown in Table 5. The results indicate that soils 597 and 598 have sufficient phosphorus and that soils 504, 508, 509, and 534 are the most deficient. This is in general agreement with the results shown by the two other methods used as indicators of phosphate response.

DISCUSSION

It has already been pointed out that there is a relationship between the PO_4 content of corn sap and the response of corn to phosphate fertilization in most of the soils tested. This relationship may be better seen by the rearrangement of the data, as shown in Table 6. In this grouping there are only three soils which are not placed in the same group by all three of the methods used. Soils 506 and 597 are in reverse order in PO_4 content of the sap and soil 507 is listed as medium rather than low by the Truog test. Such discrepancies might be expected in view of the conditions under which the experiments were conducted and the widely different methods used.

TABLE 6.—*Relative response of soils to superphosphate as shown by crop yield, PO_4 content of sap, and Truog available PO_4.*

Response	Soil number		
	Yield	PO_4 content of sap	Truog available PO_4
None	597 598	598 506	597 598
Medium	503 506	503 597	506 503 507
High	504 507 508 509 534	504 507 508 509 534	504 508 509 534

The data presented indicate somewhat higher concentrations of PO_4 in the sap than was found under field conditions (9) and are not sufficient to warrant the suggestion of numerical values for ample supplies of PO_4 in the plant sap. Under the conditions of the ex-

periment it might be expected that the amounts found in the corn would be different from those found in corn growing in the field because of the limited amount of sunshine, especially during the latter part of the growing season, and because of the smaller feeding area of the plants in the 2-gallon pots. With these two factors in mind, however, it is of interest to compare the average values obtained with the values given by Pettinger (8) for the expressed juice. Inasmuch as his results are expressed as p.p.m. of P_2O_5, it is necessary to convert these values into p.p.m. of PO_4. This will give values of 134 p.p.m. for very deficient, 134 to 268 p.p.m. for moderately deficient, and over 268 p p m. for ample supplies of PO_4. On this basis, none of the soils could be considered as very deficient, whereas soils 503, 504, 507, 508, and 509 were moderately deficient in the untreated condition, and soil 598 was just on the border. Untreated soils 506, 534, and 597 also showed ample concentrations of phosphate in the corn sap. As has already been suggested, the conditions of the experiment were not ideal and it is surprising that the agreement in actual numerical values is so close when it is further considered that the two methods of obtaining the sap were so different.

It will be noted that the amounts of PO_4 found in the exuded sap and the amounts found in the expressed juice by Pettinger are both much higher than those found in expressed juice by Gilbert and Hardin (2). The reason for this difference may lie in the part of the plant used and the methods used in analysis. These latter workers used the juice from the upper part of the corn stalk, whereas the juice from the section just above the ground was used by Pettinger. The sap used in the present investigation was collected from the cut end of the plant at about the same height. It would seem probable that phosphorus utilization occurs to a much greater extent in the growing parts of the plant and that much of the phosphorus absorbed by the corn had been utilized in the lower leaves. Consequently, only a small part of the absorbed inorganic phosphorus would be found in the sap of the top part of the plant. The differences between the results of Gilbert, *et al.* (2, 3) and of McCool and Weldon (6) cannot be explained by the part of the plant used, inasmuch as these latter workers found more PO_4 in the leaves than in the stem. However, their analyses showed total PO_4, whereas those of Gilbert and his co-workers showed only inorganic phosphates.

One other factor noted by Pettinger in the expressed juice of corn deserves attention. He noted a correlation between the amount of juice expressed and the yield of corn. The amounts of sap collected in the greenhouse from the corn were much smaller than those found in the field, but in general it was found that the amount of sap was correlated with the size of the plant from which it was collected. This would indicate, therefore, that there was a slower movement in the sap in smaller plants or in plants making poorer growth. It also suggests that in phosphorus-deficient plants two factors may operate, *viz.*, (a) there may be a lower concentration of phosphate in the plant sap and (b) there may be a slower movement of the phosphate present to the growing points in the plant.

The data here presented seem to indicate that the method of sap analysis presents possibilities in the study of phosphate availability in soils. However, it is very probable that there are a number of factors which may possibly affect the phosphate concentration of the plant sap. Among such factors may be mentioned the age, rate of growth, and general metabolic condition of the plant at the time of cutting, the moisture content and the availability of other plant food nutrients in the soil, and such environmental factors as light and temperature at time of collection. Further studies should be made of these factors and of the concentration of phosphate in the plant sap under field conditions before definite conclusions can be reached regarding the possibility of establishing critical concentrations which would indicate the deficiency of available phosphate in the soil.

SUMMARY AND CONCLUSIONS

The determination of the PO_4 content of the exuded sap of corn plants is suggested as a method for measuring phosphorus deficiency in the soil. This sap appears to offer all the advantages of the expressed juice without such disadvantages as the possibility of change in composition due to expression. In addition, it is easier to collect and analyze than is the expressed plant juice. The amount of inorganic PO_4 found in corn sap varied from 62 to 602 p. p. m. Usually the amount increased with the age of the plant.

The results obtained under greenhouse conditions show a good correlation with the response of corn to phosphate fertilization and also with the water-soluble PO_4 and the available PO_4 as determined by the Truog method.

The data seem to justify additional tests with the method in order to ascertain limiting concentrations of PO_4 for normal growth. Certain factors, such as light, temperature, moisture condition of the soil, supply of other nutrients, age and metabolic condition of the plant, and height of cutting, may affect the results and these should be considered in further studies of the method.

Although no data are presented in this paper to show the concentrations of other nutrients in the exuded sap it would appear that the method might be used to advantage in a study of the availability of various elements, particularly nitrogen and potassium.

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The meetings of this Commission will be held in Copenhagen, Denmark, August 10 to 11, 1933, and will be largely devoted to a discussion of the three following subjects: (1) Microbiological analysis of soils as an index of soil fertility; (2) the present status of our knowledge of nitrogen-fixation by leguminous plants, and the problem of soil inoculation; and (3) the rôle of micro-organisms in the decomposition of organic matter in soils and in composts and the formation of humus.

All interested in this Commission are cordially invited to attend the meetings and to present a paper dealing with one of the subjects outlined above. The president of the Commission should be notified immediately of intention to attend the meetings.

JOURNAL

OF THE

American Society of Agronomy

Vol. 25 | March, 1933 | No. 3

SIZE OF KOREAN LESPEDEZA SEED IN RELATION TO GERMINATION AND HARD SEED[1]

Gordon K. Middleton[2]

A rapid decrease in the hard seed content of samples of Korean lespedeza (*Lespedeza stipulacea*) from November through January, but with very little decrease in the two following months, was recently reported by the writer.[3] The average percentage of hard seed found in 10 samples for November, January, and March was approximately 47, 12, and 11, respectively.

This general seasonal trend has been observed for 3 years and during this time there have been very few instances in which samples tested in February and March have shown an actual germination below 70%, provided the total viable percentage was above 90. The results secured with the 10 samples reported above were carefully checked against reports on 500 samples tested during the winter of 1931–32 by the State Seed Laboratory, North Carolina Department of Agriculture, and it was found that there was very good agreement for all samples of well-matured, bright, plump seed. Among the many lots tested, however, were a few of second grade seed which showed a high percentage of hard seed even when tested late in the spring. Studies conducted with certain of these lots have shown a definite relationship between size of seed and hardness, and are reported in this paper.

MATERIALS AND METHODS

From a total of 500 samples of Korean lespedeza, five pairs which had been separated on a commercial grading machine into large and small seed were selected and tested during the late spring of 1932, the germination of the large seed being compared to that of the

[1]Contribution from the Division of Farm Crop Seed Improvement, North Carolina Agricultural Extension Service, Raleigh, N. Car. Published with the approval of the Director as Research Paper No. 61 of the North Carolina Agricultural Experiment Station. Received for publication June 28, 1932.

[2]Seed Specialist.

[3]Middleton, Gordon K. Hard seed in Korean lespedeza. Jour. Amer. Soc. Agron., 25:119–122. 1933.

small in each case. In addition, a number of samples were split into three sizes in the laboratory by screens and the separations tested against the original sample.

The tests were made in an electric germinator at a temperature ranging between 25° and 30°C, the duration of the tests being 14 days. For a germination sample, 100 seed were used and all tests run in duplicate except in a few cases where it was desired to use statistical methods, where three replications were run.

EXPERIMENTAL WORK

When cleaning Korean lespedeza seed, certain growers have followed a practice of shrinking heavily any samples in which dodder occurs in an effort to eliminate it from the better grade seed. Upon comparing the germination of the large and small seed from a number of these split samples it was noted that the large seed were apparently giving much better germination and a lower percentage of hard seed than were the small seed.

Five pairs of samples, each pair coming originally from the same lot of seed, were selected and tested in March 1932. The number of seed per gram was determined and used as a measure of relative size. The results secured are shown in Table 1. Student's method was used in comparing the data from the large and small seed samples. The results show a significant difference in germination and in hard seed, but not in total viable seed.

TABLE 1.—*Relation of size of Korean lespedeza seed to germination and hard seed.**

Sample No.	No. seed per gram		Germination, %		Hard seed, %		Total viable seed, %	
	Large	Small	Large	Small	Large	Small	Large	Small
1307.......	540	685	74.0	43.5	16.5	36.5	90.5	90.0
1313.......	618	706	76.5	47.5	17.5	52.5	94.0	100.0
1314......	518	625	82.0	63.0	11.5	30.5	93.5	93.5
1318	555	658	73.0	59.0	18.0	37.5	91.0	96.5
1119......	560	730	81.0	61.5	16.0	30.5	97.0	92.0
Average	558.2	680.8	77.3	54.9	15.9	37.5	93.2	94.4

*Samples separated by commercial machine, 1931 crop; tested March 26 to April 9. Raleigh, N. C.

Two of the samples, Nos. 1313 and 1314, were selected for further study. The large and small seed from the same lot were mixed, the hulls rubbed off by hand, and the seed regraded Two screens with round holes were used, the perforations being 1/18 and 1/20 inch in diameter. Those seed remaining on top of the 1/18 inch screen were designated large, those remaining on the 1/20 inch as medium, and those passing through as small. The medium-sized seeds were discarded and the large and small sizes retested for germination. Four samples of each lot were tested, the results averaged, and the probable error worked out by Bessel's formula.

The small seed contained more immature seed than did the large seed, but in this particular test only what appeared to be mature

seed were used. The results are more striking than in the former test, due to there being a better separation of the large and small seed. The percentage germination of the large seed in sample No 1313 was 96 ± 0.38 and of the small seed 35 ± 1.79, while the hard seed for the two sizes was 1.5 ± 0.43 and 65 ± 1.79, respectively. Total viable

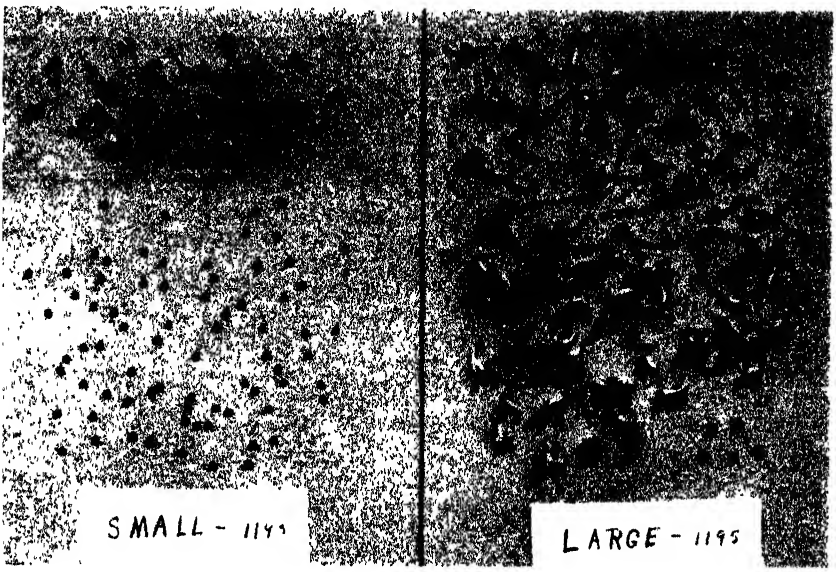

FIG. 1.—The relation of size of seed to germination and hard seed in Korean lespedeza. The photograph was made when the seed had been in the germinator only 60 hours. At the end of a 14-day period only 1 seed in the large lot proved to be hard, while 65 were still ungerminated in the small lot. These small hard seed were left in the germinator for 33 days without further germination. They were then removed, scarified with sand paper, and replaced in the germinator. In 48 hours, 100% germination was secured. This proved true in the case of duplicate samples of two different lots of seed.

seed in the large seed fraction was 97.5% and in the small seed 100%. Quite similar results were obtained with sample No. 1314.

To show this relationship between size and hardness more clearly, the two sizes of seed from sample No. 1313 were mixed in different proportions, varying from 100% large to 100% small, and tested. The results obtained are reported in Table 2.

To obtain information as to what percentage of the seed falls into each of these three sizes, and as a still further check on the relation of size of seed to hardness, five additional well-matured samples were graded and tested. In these five samples it was found that from 7.4 to 18.5% of the seed were small enough to pass through the 1/18-inch mesh and to fall into one of the two smaller grades. Counts made to determine the percentage of green seed in each grade showed that the smaller seed fractions contained most of these. In preparing samples for the germination test, however, these immature seed were not removed as they were in making the tests reported in Table 2. The

TABLE 2.—*Showing the effect of a variable percentage of small seed on germination and hard seed content of Korean lespedeza, sample No. 1313, April 1932, Raleigh, N. C.*

Percentage of seed of different sizes		Germination, %	Hard seed, %	Total viable seed, %
Large	Small			
100	0	96	1.5	97.5
75	25	85	13.0	98
50	50	62	35	97
25	75	55	44	99
0	100	35	64	99

results obtained are reported in Table 3. In Fig 1 is shown the comparative germination of large and small seed taken from the same sample.

TABLE 3.—*Relation of size of Korean lespedeza seed to germination and hard seed.**

Sample No.	Size†	Percentage by weight	Green, %	Germination, %	Hard seed, %	Total viable seed, %
1195..	Ungraded	—	—	79.5	18.5	98.0
	Large	84.7	0.5	96.5	1.0	97.5
	Medium	11.8	5.0	49.5	49.5	99.0
	Small	3.5	14.0	32.0	65.0	97.0
1193..	Ungraded	—	—	87.0	10.5	97.5
	Large	86.8	0.5	95.0	2.0	97.0
	Medium	11.0	6.0	47.0	47.5	94.5
	Small	2.2	6.0	20.5	72.0	92.5
1166..	Ungraded	—	—	88.0	9.5	97.5
	Large	81.5	2.0	98.0	2.0	100.0
	Medium	15.5	4.0	69.5	28.5	98.0
	Small	3.0	11.0	42.0	55.0	97.0
1509..	Ungraded	—	—	96.5	6.0	97.5
	Large	92.6	0.0	98.0	1.0	99.0
	Medium	6.0	1.0	73.0	26.0	99.0
	Small	1.4	2.0	42.0	54.0	96.0
1511..	Ungraded	—	—	92.0	6.5	98.5
	Large	87.9	0.5	95.5	3.0	98.5
	Medium	10.4	1.0	61.0	38.0	99.0
	Small	1.7	6.0	51.0	48.0	98.0

*Percentage of seeds that pass through different screens and percentage of green seed shown by groups. Tested April 21 to May 5, 1932, Raleigh, N. C.

†Seed which would not pass 1/18-inch perforation were designated as large, while those passing through but remaining on 1/20-inch and those passing through 1/20-inch perforation were called medium and small, respectively.

SUMMARY AND CONCLUSIONS

Samples of Korean lespedeza seed, separated into different sizes by screens, were tested for germination in the laboratory in the late spring of 1932.

The data show a definite relationship between size of seed and hardness, the smaller seed having the higher percentage of hard seed.

Five samples of seed, each separated into three sizes, showed only 1 to 3% hard seed in the large seed fractions, while the smallest size contained from 48 to 72% hard seed. Seed intermediate in size were intermediate in percentage of hard seed.

The small seed fractions contained more immature seed than did the large seed fractions, but in the samples used maturity did not obscure the relationship existing between size and hardness. In some samples the green seed were removed while in others they were left in and in each case a close correlation was found between size of seed and hardness.

The data reported show that where a lot of seed is split during the grading process the percentage of hard seed in the small seed fraction will be high. The lower germination of the small seed will be partially but not entirely offset by the larger number of seeds per pound. Field tests would be valuable in further determining the comparative value of different sizes of seed, but the tests reported show that care must be exercised in the use of second grade seed. It would seem that where such seed are to be used, the tests should be delayed as late as possible, and the rate of seeding to be used based on the actual germination obtained.

In an earlier paper, the author presented data to show that when germination tests were made upon samples of well-matured, bright, plump seed in November or December, the deduction of approximately 15% from the total viable seed would give a safe estimate as to the actual germination that might be expected at planting time. The data presented in this paper are not in conflict with the previous statement, since here we have been dealing entirely with second grade seed, or screenings, which can easily be detected by the appearance of the sample.

PERSISTENCE OF VIABILITY OF SWEET CLOVER SEED IN A CULTIVATED SOIL[1]

T. E. Stoa[2]

The "hard seed" character common to many legumes is well known. How effective this adaptation of nature is in preserving the species in land under cultivation is perhaps not so fully appreciated.

The unusual effectiveness of this character in preserving sweet clover has been under observation in some of the agronomy field plats of the North Dakota Experiment Station during the last 14 years. In the plats referred to, sweet clover seed was allowed to mature in 1918. Observations reported herewith are those connected with the seed which shattered before it could be harvested, or shattered in the process of harvesting. The fields have been under cultivation and

[1]Contribution from the Department of Agronomy, North Dakota Experiment Station, Fargo, N. Dak. Publication authorized by Director, July 19, 1932. Received for publication July 29, 1932.

[2]Assistant Agronomist.

cropped each year. The soil is Fargo clay. The 51-year average annual rainfall at Fargo is 22.79 inches. Since 1919 the average annual precipitation has been 20.09 inches, ranging from 13.89 to 23.95 inches.

In a sweet clover trial seeded in 1917 in a section of the plant breeding nursery, sweet clover seed was allowed to mature in 1918 on two 1/20 acre plats. The remainder of this section, also in sweet clover, did not mature seed. Since that time this section in the nursery has been used for the regular small grain nursery, alternating with an intertilled crop, such as corn or soybeans. Volunteer sweet clover seedlings from seeds which have become permeable and have germinated have been more or less in evidence each year. The cropping method, however, has resulted in early destruction of all volunteer seedling sweet clover plants.

In 1932, 14 years later, in preparing the land for soybeans, the two plats or strips through this section which matured the seed in 1918, were still plainly visible, due to the volunteer seedling growth of sweet clover which was present.

The record is even more specific in another field, Section 20, Field L. A sweet clover seed crop was matured and harvested in this field in 1918, considerable seed having shattered. The cropping history of this field since that time and the observations which have been made on the volunteer sweet clover from the seed which shattered in 1918 are interesting.

The field was fall plowed in 1918 and planted to corn in 1919. Sweet clover plants which may have volunteered that first year were destroyed by early cultivation. After removing the corn in 1919 the land was seeded to winter rye. A full stand of sweet clover seedlings appeared with the rye in 1920. This sweet clover crop was removed for hay in 1921 and the land plowed early. A second full stand of volunteer seedlings emerged early in the spring of 1922 and was destroyed in preparing the land for corn. In the spring of 1923 another full stand of seedling sweet clover emerged and was destroyed before seeding small grain. Many more seeds brought to the surface, however, were permeable and these germinated promptly, resulting in the fourth volunteer crop since 1918. This volunteer growth was effectively destroyed by early fall plowing in preparation for seeding winter rye. The rye became a companion crop for another volunteer crop of sweet clover in 1924 (Fig. 1). This volunteer growth too was destroyed by early fall plowing.

The sixth volunteer crop came on early in 1925 before preparing the land for corn. The seventh crop came on in 1926 when the land was used as a small grain nursery. This growth was destroyed by wheel hoeing and weeding. In 1927, the land was seeded to field peas, and the eighth crop, a fair stand of clover, appeared with the peas and was destroyed by early fall plowing. The ninth volunteer crop came on when oats were grown in this field in 1928. This volunteer growth was removed as hay in 1929 and the land treated as fallow. In 1930, a 60 to 70% stand of sweet clover seedlings was present in the barley crop and was destroyed by early fall plowing. Early and subsequent

tillage for corn destroyed any volunteer plants which may have appeared in this field in 1931.

The land was seeded to barley again in 1932. Another volunteer crop of sweet clover seedlings, a fair stand, emerged with the barley. This new growth makes the eleventh distinct volunteer crop of sweet

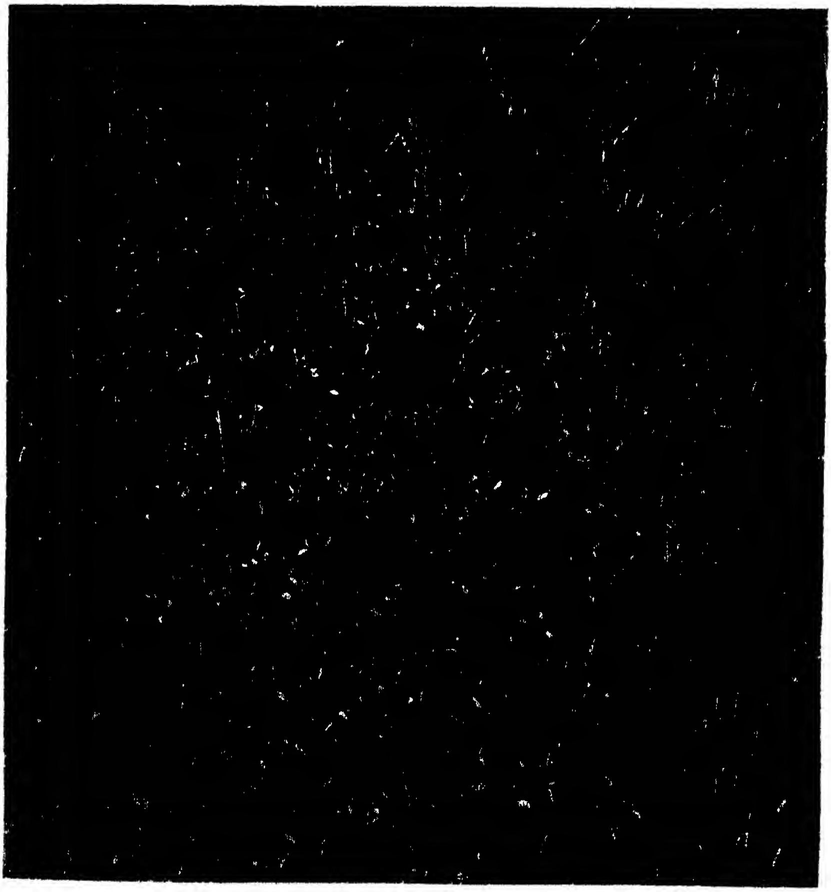

FIG. 1.—A full stand of volunteer sweet clover seedlings in rye stubble, Section 20, 1924. This was the fifth distinct crop of volunteer sweet clover in this field since 1918.

clover which has come on in this field in the 14-year period since 1918. Delayed tillage in some years, allowing more complete emergence, and more careful observations would in all probability have made possible recording volunteer growth in each of the 14 years since 1918.

A few other fields on the agronomy farm where sweet clover seed has matured have shown the same characteristic preservation of the seed (Figs. 2 and 3). At no time since 1918 have plants been allowed to mature seed in these fields, and such growth as has appeared in succeeding years is from the original shattered hard seed. In cases

where there were originally plats of yellow blossom and white blossom sweet clover in the same fields, the identity and location of these

Fig. 2.—Plowing under second year's growth of volunteer sweet clover, Section 3, in preparation of the land for corn. This volunteer growth, May 23, 1922, is from seed which matured and shattered in 1919. (See Fig. 3.)

Fig. 3.—Another view of Section 3, 2 years later. Plowing under volunteer sweet clover, July 1924, years after the hard seed shattered in this field. Four more crops have volunteered in this field since this photo was taken. Recent soil observations indicate a considerable number of hard viable seeds still present.

original plats has been noticeable whenever the seedling sweet clover has been carried over into the second year and allowed to blossom. One may well speculate as to how much these and similar, but less conspicuous factors, may be upsetting the uniformity of experimental soil and influencing experimental results.

Careful examination and washing of soil samples from Sec. 20, where to date 11 distinct volunteer crops have been accounted for, have shown some interesting results. In about a peck of surface soil, taken in the fall of 1922, there were 934 sweet clover seeds. In the fall of 1926 from duplicate soil samples, each representing an area of soil 6 x 8 inches on the surface and 6 inches deep, there were present on the average 224 seeds. In 1929, there were found in a similar area an average of 48 seeds, and in 1931, an average of 40 seeds, hard but still viable. It may be expected, therefore, that sweet clover will continue to volunteer in this field for some time to come. This soil has a fairly high lime content, with a pH value of 7.0 on June 3, 1932.

Only a portion of the hard seeds become permeable each year. These germinate readily early in the spring. There is usually no germination in mid-summer on fallow land, or in the fall. Sweet clover seeds then present in the soil apparently are not in condition to absorb moisture and start growth. Seeds separated from soil samples in the fall are always nearly 100% hard.

THE EFFECT OF SEED INOCULATION AND OF A NITROGEN FERTILIZER ON THE SURVIVAL OF RED CLOVER PLANTS GROWING IN SOIL PREVIOUSLY TREATED WITH SODIUM CHLORATE[1]

W. E. HAINES[2]

Various chemicals have been used to eradicate weeds. Of these, sodium chlorate has proved to be one of the most effective and has been used extensively both by experimental workers and by farmers.

An objection to the use of sodium chlorate has been the residual toxic effect upon farm crops planted after the weeds were eradicated. There are many cases on record where the soil was either sterile for a period after the application of the chlorate, or, if crops grew, the yields were reduced. From experiments that have been made, it is known that the soil is not injured permanently, and that, in general, a year or two between the application of the chlorate and the planting of farm crops is ample time to allow the toxic effects of the chlorate to disappear. In some cases, the toxic effect of fall applications had disappeared by the following spring.

[1]Contribution from the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station, St. Paul, Minn. Presented to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of master of science. Paper No. 1125 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication July 27, 1932.

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In the present experiment, an attempt was made to counteract the toxic effects of sodium chlorate on red clover plants by the use of a nitrogen fertilizer and by inoculation of the clover seed. The tests were carried out in a greenhouse at University Farm, St. Paul, in the spring and summer of 1930.

MATERIALS AND METHODS

Unsterilized field soil was treated with sodium chlorate in solution and placed in 8-inch pots. Two rates of chlorate application were used, *viz.*, 2 pounds and 4 pounds per square rod, based on a volume of soil 1 square rod in area and 5 inches in depth. Seedings of red clover were made at 10 weekly intervals after the soil was treated with chlorate. Both inoculated and uninoculated red clover seed was sown in duplicate pots for each test, the following comparisons being made: (1) In chlorate-treated soil; (2) the same, but with the addition of ammonium sulfate at the rate of 1 pound per square rod; and (3) in soil of the same nature not treated with sodium chlorate. All pots, planted and unplanted, were watered alike.

The plants growing in the chlorate-treated soil emerged at the same time as those in the untreated check soil and appeared to be no different from them for 5 to 14 days after emergence. The first sign of chlorate injury was a whitening of the leaf edges sometimes preceded by a yellow color. In this test, the toxic effect of the chlorate had not disappeared from the soil at the end of 10 weeks. The soil was always kept in a moist condition and the temperature was above 70°F, except for an occasional period of a few hours.

Counts of clover plants were made 1 week after emergence and again at the end of 60 days, when the plants were removed from the soil and nodule counts were made. That some viable bacteria were present in all cases was indicated by the nodulation of some clover plants in each pot.

EXPERIMENTAL RESULTS

There was no significant difference between the results obtained from the 2-pound and the 4-pound chlorate applications in this test. In Table 1 the percentage survivals of clover plants grown from inoculated and uninoculated seed in chlorate-treated soil with and without the addition of ammonium sulfate and in soil not receiving any chlorate are given. The results from the 2-pound and the 4-pound chlorate applications have been averaged.

If the toxic effect of the chlorate decreased as the interval between application of the chlorate and seeding became greater, the percentage survival of the plants would be expected to be higher. That the percentage of the plants surviving in this test was in general lower in the later plantings may have been due to conditions in the greenhouse being less favorable for the growth of the plants during the latter part of the test. It was not possible to control the temperature in the greenhouse and it was often quite high during the latter part of the test.

TABLE 1.—*Percentage survival of red clover seeded at weekly intervals in soil treated with sodium chlorate and in untreated soil.**

Weekly intervals	Uninoculated seed			Inoculated seed		
	Soil 1	Soil 2	Soil 3	Soil 1	Soil 2	Soil 3
1	59	79	100	76	91	100
2	78	87	100	91	64	100
3	54	85	100	74	92	100
4	34	53	95	53	70	100
5	53	74	96	45	90	93
6	49	57	89	74	92	94
7	45	54	100	64	94	100
8	12	54	41	30	63	82
9	45	20	70	75	48	100
10	35	70	90	63	85	100
Average	46	63	88	65	79	97

*Soil 1 treated with chlorate; soil 2 treated with chlorate and with ammonium sulfate added; and soil 3, untreated.

SUMMARY AND CONCLUSIONS

The percentage of clover plants surviving from treatments on the chlorate-treated soil where both inoculation and ammonium sulfate were used was still significantly lower than the percentage survival of plants growing in the untreated check soil.

Inoculation of the clover seed, the application of ammonium sulfate, and a combination of the two increased the survival of clover plants on the chlorate-treated soil. Inoculation increased the survival of clover plants on the untreated soil.

Ammonium sulfate gave the least increase in percentage survival of the clover plants growing in the chlorate-treated soil, but the increase was quite significant. Inoculation of the seed was next, with the combined treatment giving the largest increase. In the case of plants growing in the chlorate-treated soil, there was a correlation of $.65 \pm .04$ between the percentage of plants surviving from a treatment and the average nodules per plant on the plants which survived from that treatment.

No data were available for similar tests under field conditions. The writer believes that such field tests would be desirable as these experiments indicated that it may be possible by such means to grow crops on small areas which have received applications of chlorate much sooner than could be done otherwise. It would be desirable to test different amounts and types of nitrogen fertilizers, using several common field crops.

A STATISTICAL STUDY OF CERTAIN CHARACTERS OF THE ALFALFA PLANT CONCERNED WITH SEED PRODUCTION[1]

BERNHARD DANN AND L. R. WALDRON[2]

This paper is concerned with showing certain data in statistical form which were previously presented by Dann (2).[3] The data, taken in Germany, were in regard to the alfalfa plant and were concerned, among other things, with the weight of plant, weight of seed produced per plant, number of racemes per plant, number of pods per raceme, number of seeds per pod, and sterile racemes in percentage of fertile. Data for the foregoing six characters are available for 236 plants.

Studies have been made by various individuals upon the alfalfa plant with respect to the factors affecting tripping and pod formation. The work of Piper, *et al.* (4) is important in this regard, but no attempt will be made here to review the literature. Carlson (1) evidently found that under natural conditions of development many-flowered racemes formed proportionately more pods than did fewer-flowered racemes. Correlation data were not secured.

EXPERIMENTAL RESULTS

Only a brief outline of the experimental work need be given here as ample details are to be found in the original article (2). The 236 plants, of the *media* variety, were cultivated in the Halle University garden and were planted in 1926 on uniform soil 30 cm apart each way. The plants were kept from the ground by staking. When most of the pods had turned brown, the plants were cut and stored for drying and future note taking. At time of note taking the plants were weighed and the racemes and pods per plant were counted. A sample of 150 pods per plant was taken to learn the number of seeds per pod. The total pods per plant were threshed to obtain seed yields per plant. The means, standard deviations, and coefficients of variability are shown in Table 1.

TABLE 1.—*Statistical constants of six alfalfa characters secured from 236 plants, weight taken in grams.*

	Mean	Standard deviation	Coef. of variability %
Seed weight per plant, grams	4.84	4.37	90.2
Total weight of plant, grams	85.85	42.24	49.2
Total racemes per plant	231.1	172.24	74.6
Pods per racemes	4.9	2.45	50.4
Seeds per pod	2.3	0.85	37.6
Sterile racemes in % of fertile	56.7	65.81	116.1

[1]Contribution from the Department of Agronomy, North Dakota Agricultural Experiment Station, Fargo, D. Dak. Published with the approval of the Director. Received for publication August 2, 1932.

[2]Graduate Student and Plant Breeder, respectively.

[3]Reference by number is to "Literature Cited," p. 189.

Between 5 and 6% of the weight of the plants was harvested as seed. Brought to an acre basis and calculated to a complete stand, the above averages for plant weight and seed weight per plant indicate a crop yield of over 4 tons per acre of which something like 5%, or 400 pounds, would be seed. This is a comparatively high yield of seed. While the number of racemes per plant runs over 230, one notes a very appreciable percentage of racemes from which all blossoms and pods had dropped. The percentage of sterile racemes of the total is calculated to be 36. The number of flowers per raceme, when pods were present, was considerably larger than the number of fertile pods per raceme. Thus it is evident that with the heavy production of seed there has been a heavy flower loss. The mean number of seeds per pod (2.3) is rather higher than that found in several experiments cited by Piper, *et al.* (4) where a maximum average of 2.38 for one experiment is reported.

The weight of seed in this experiment was found to be 1.86 grams per 1,000 seeds, a figure which agrees well with the weight given by Westgate (5) for samples of "sand lucern" from Europe.

The coefficients of variability are high in all cases. The coefficient for seed production is nearly twice as great as for weight of plant, a fact not surprising to one who has observed the marked differences in amount of seed carried by individuals in a planting where the units are spaced to allow for individual plant expression. This is particularly true in a general population where no strict selection has been practiced, as in the present instance. These data seem to indicate a similarity to alfalfa seed crops produced in this country, except that this particular crop was considerably heavier than that usually found under field conditions in the United States.

CORRELATION DATA

Total and partial correlation data were calculated between five of the six characters. Correlations with the character sterile racemes in percentage of fertile were not calculated as the advantage was not evident. In addition, the distribution of the frequencies in this case was very skew and partial correlations would not have been valid. The data appear in Table 2.

With 236 variates, correlation coefficients as low as $\pm$ 0.13 begin to take on significance. One notes that the correlation between weight of seed and the other characters is rather strongly positive and is highest with weight of plant. None of the partial correlation coefficients where weight of plant is concerned show any radical change from the 0-order coefficient, but all show decreases. The correlation between weight of seed and number of racemes is comparatively high, 0.538, but this drops to essentially zero with the partial coefficients in all cases where weight of plant is held constant. A marked correlation exists between seed weight per plant and pods per raceme. With three of the partial coefficients a noticeable decrease came about in the amount of correlation. The correlation between weight of seed per plant and seeds per pod is comparatively high at 0.566, but this is appreciably reduced where the pods per raceme is held constant in the partial correlations.

TABLE 2.—*Total and partial correlation coefficients from the data given by Dann (2) on weight of seed, weight of plant, total racemes, pods per raceme, and number of seeds per pod for 236 alfalfa plants.**

Weight of seed—Weight of plant							
0-order .729	Constants: Racemes .585	Pods .597	No. seeds .707	Racemes, pods .463	Racemes, No. seeds .498	Pods, No. seeds .618	Racemes, pods, No. seeds .436
Weight of seed—Total racemes							
.538	Plant wt. —.053	Pods .426	No. seeds .581	Plant wt., pods —.019	Plant wt., No. seeds .069	Pods, No. seeds .490	Plant wt., pods, No. seeds .062
Weight of seed—Pods per raceme							
.684	Plant wt. .519	Racemes .622	No. seeds .547	Plant wt., racemes .517	Plant wt., No. seeds .367	Racemes, No. seeds .443	Plant wt., racemes, No. seeds .366
Weight of seed—Seeds per pod							
.566	Plant wt. .524	Racemes .606	Pods .325	Plant wt., racemes .525	Plant wt., pods .375	Racemes, pods .412	Plant wt., racemes, pods .379
Weight of plant—Total racemes							
.770	Seed wt. .655	Pods .731	No. seeds .779	Seed wt., pods .656	Seed wt. No. seeds .640	Pods, No. seeds .740	Seed wt., pods, No. seeds .638

	Weight of plant—Pods per raceme						
	Seed wt.	Racemes	No. seeds	Seed wt., racemes	Seed wt., No. seeds	Racemes, No. seeds	Seed wt., racemes, No. seeds
.522	.048	.408	.444	.070	.098	.277	.073
	Weight of plant—Seeds per pod						
	Seed wt.	Racemes	Pods	Seed wt., racemes	Seed wt., pods	Racemes, pods	Seed wt., racemes, pods
.309	—.184	.354	.041	—.001	—.202	.176	—.019
	Total racemes—Pods per raceme						
	Seed wt.	Plant wt.	No. seeds	Seed wt., plant wt.	Seed wt., No. seeds	Plant wt., No. seeds	Seed wt., plant wt., No. seeds
.363	—.007	—.072	.363	—.052	.066	.029	.005
	Total racemes—Seeds per pod						
	Seed wt.	Plant wt.	Pods	Seed wt., plant wt.	Seed wt., pods	Plant wt., pods	Seed wt., plant wt., pods
.110	—.281	—.211	—.108	—.215	—.287	—.201	—.209
	Pods per raceme—Seeds per pod						
	Seed wt.	Plant wt.	Racemes	Seed wt., plant wt.	Seed wt., racemes	Plant wt., racemes	Seed wt., plant wt., racemes
.535	.246	.461	.535	.260	.254	.457	.255

*In the first column is found the total correlation values. The next three columns show the partial correlation coefficients of the first order, the next three columns those of the second order, and the last column those of the third order. The characters held constant are given above the various coefficient values.

The correlation between weight of plant and pods per raceme is above 0.5 but drops essentially to zero where weight of seed per plant is held constant in the calculation of partial coefficients. There is an apparent significant total correlation between weight of plant and seed per pod, but evidently this is largely fictitious as shown by the partial coefficients. When the three other variables are held constant the correlation drops to near zero. This is not surprising as an organic correlation would scarcely be expected between these two characters. Remarks similar to the foregoing are applicable to the relationship between pods per raceme and total racemes. The net correlation between total racemes and seeds per pod is significantly negative when seed weight, plant weight, and number of pods are held constant. Considering the last item, there seems to be a real positive relationship between seeds per pod and pods per raceme. The net correlation when seed weight, plant weight, and total racemes are held constant is still statistically significant.

In summarizing, the total correlations between seed weight per plant and the four other characters are moderate to rather pronounced. The strictly net correlations are moderately high in three cases, but where total racemes are concerned the net correlation drops to near zero. The total plant weight is positively correlated rather strongly with total racemes, pods per racemes, and seeds per pod with respect to the o-order, but the strictly net correlation, of the third order, remains significant only where total racemes is correlated with weight of plant. The third-order correlation is 0.638 as compared with the o-order coefficient of 0.77. This is in marked contrast to the third-order coefficient where total racemes is correlated with weight of seed. In this case the value is near zero. The correlations of total racemes with pods per raceme and seeds per pod are of little importance. A true correlation exists between seeds per pod and pods per raceme.

REGRESSION COEFFICIENTS

Both total and partial regression coefficients were calculated. The total coefficients were calculated by the usual formula, $b = r_{12}\frac{\sigma 1}{\sigma 2}$. Fisher (3, p. 132) has outlined the method for the calculation of regressions where several independent variables are concerned. The two series are to be found in Table 3.

TABLE 3.—*Total and partial coefficients of the regression of seed weight on the independent variates as indicated.*

	Total	Partial
Plant weight	0.075	0.047
Racemes per plant	0.014	0.001
Pods per raceme	1.219	0.501
Seeds per pod	2.910	1.385

The partial coefficients are decidedly less than the total in all cases; with respect to racemes per plant the partial coefficient is only one-tenth that of the total. The partial coefficients may be considered

the more valuable. It is of interest to present these in percentages of the means and in actual deviations. A uniform deviation of 10% in seed weight per plant was calculated for the dependent variable and corresponding to this deviation the deviations of the four independent variables, from the mean, are given, as follows:

Character	% deviation	Actual deviation
Weight of plant	12.0	10.3 grams
Racemes per plant	151.8	351 racemes
Pods per raceme	19.7	1 pod per raceme
Seeds per pod	15.2	0.3 seed per pod

A deviation of 10% from the mean in seed weight per plant is equal approximately to ½ gram. The remarkably high deviation required in racemes per plant to effect a 10% deviation in seed weight, amounting to many more than the mean number of racemes per plant, is evidently due in considerable measure to the rather high percentage of sterile or "stripped" racemes, racemes where no successful fertilization has taken place. An examination of almost any piece of alfalfa in a ripening condition reveals the presence of a considerable proportion of empty racemes. Carlson (1) reported 18% of the racemes studied by him as "stripped." In addition to this, racemes which bear pods show loss of flowers in varying degrees.

Having the needed data to calculate partial coefficients, it was a simple matter to calculate the multiple correlation coefficients of plant weight, number of racemes, pods per raceme, and seeds per pod upon the weight of seed per plant, according to the formula given by Fisher (3, p. 226). The coefficient was found to be 0.84 which is a highly significant value. This measures, in a sense, the combined participation of the four variates mentioned in seed production.

SUMMARY

Alfalfa in an experimental garden under German conditions produced a heavy seed crop generally similar, as shown by the means, to alfalfa seed crops in this country.

With four independent variables distinctly significant correlations were found between weight of seed per plant (dependent) and weight of plant, pods per racemes, and seeds per pod, for the zero, first, second, and third orders. Only total racemes was correlated positively and significantly with weight of plant for the various orders.

Total and partial regression coefficients were calculated. With regard to the partial coefficients, a deviation of but 12% in plant weight accounted for a deviation of 10% in weight of seed per plant. It required a relatively enormous deviation of racemes per plant to result in a similar deviation of seed.

The multiple correlation coefficient of the four independent variables on weight of seed per plant was 0.84, a highly significant value.

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ANALYSIS OF YIELD IN CERTAIN OAT VARIETIES[1]

R. E. FORE AND C. M. WOODWORTH[2]

At the present time very little is known about the inheritance of seed yield in oats. Of the varieties now in existence some give high yields, some moderate yields, and some low yields, but the reasons for these differences are, in the main, unknown. Since yield is a complex character, it seems advisable for the plant breeder to attempt to analyze it into its constituent parts and learn how these are inherited in order to make the most progress in breeding for yield.

The purpose of this investigation was three-fold—to attempt to analyze seed yield of oat varieties into its component parts, to determine the relations existing between the components and yield, and to determine the relations existing among the components themselves.

MATERIAL AND METHODS

The data used in this study were obtained on individual plants of 20 different varieties and strains grown at the Illinois Agricultural Experiment Station, Urbana, Ill., during the summer of 1930. An attempt was made to include as many different types as possible so that genetic differences in yielding ability between varieties could be determined. Varieties differing in maturity, grain color, panicle type, and many less noticeable characters were included.

An attempt was made by the method of planting to eliminate, in so far as possible, all environmental differences so that differences found might be considered genetic. The varieties were planted in rows 16 feet long and 1 foot apart, with the plants spaced 2 1/8 inches apart in the rows. Each 16-foot row was divided into seven sections and a different variety planted in each section. Each variety was replicated 15 times, each replicate consisting of a 12-plant section and the replicates were scattered systematically thruout the plat. The early and late varieties were planted in separate adjoining plats to avoid competitive effects.

The number of plants on which data were taken varied for different varieties due to differences in stand. The end plants of each section were discarded to eliminate end-to-end varietal competitive effects, thus giving 10 plants per section with a full stand. However, a full

[1]Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois, Urbana, Ill. Published with the approval of the Director of the Illinois Agricultural Experiment Station. Received for publication August 3, 1932.

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stand was not obtained in all cases, and as only plants having a full stand on either side of them in the row were used, the number of plants per variety on which data were taken, with the exception of Illinois Hull-less which had only 43, ranged around 100, some varieties exceeding and some falling slightly below this figure.

Records for all characters were taken on each plant separately. Tillers, sterile spikelets, and panicles were counted in the field, tiller counts being made on May 5, May 21, and May 28. At the last-named date, the varieties had almost reached their tillering capacity under the conditions of this experiment. The sterile spikelet counts were made on plants of only one replicate of each variety. The panicles were removed in the field in order to prevent mixtures and loss of seed from shattering. Each plant was threshed separately by hand, and the seed weight in grams determined. Yield is considered on a plant basis thruout this paper.

To obtain the average weight of one seed, 50 seeds from each of 20 plants taken at random from each variety were weighed. The sum of these weights gave the weight of 1,000 seeds per variety. The average weight of one seed was then calculated.

The average per cent of hull was also obtained from samples of 50 seeds each, taken from 20 plants chosen at random from each variety. Each sample of 50 seeds was weighed before and after dehulling and the average per cent of hull calculated for each variety.

The average yield per panicle, average number of branches per panicle, average number of branches per whorl, and average number of whorls per panicle were calculated from the individual plant data.

In studying the yield per panicle of plants having different numbers of panicles, the plants of each variety were classified into groups according to the number of panicles per plant and the average yield per panicle of each group calculated, the varieties being kept separate.

For purposes of comparison the means of the varieties were ranked from 1 to 20 for each character, rank 1 representing the variety with the highest expression of the character as, for instance, the variety having the largest number of panicles per plant, and rank 20 representing the variety showing the lowest expression of the character. A bar diagram was drawn for the character with which comparisons were to be made, having the varieties in order from the highest to the lowest. Diagrams were then drawn for the other characters, keeping the varieties in the same order as in the first diagram. This method of comparison is illustrated in Fig. 3 where all characters are compared with yield per plant.

EXPERIMENTAL RESULTS

The means of the characters for all varieties are shown in Table 1. The probable errors are given for all characters except average weight of one seed. These data were determined from the weight of 1,000 seeds, and hence the probable errors could not be calculated.

YIELD PER PLANT

Agronomically, seed yield is the most important character of oat varieties and is receiving more attention from breeders at the present

time than any other character. Garber (6)[3] in summarizing the accomplishments of small grain breeding, states, "In this paper most emphasis has been placed on the increased yields...because this, in the last analysis, is the most important character, yet many other characters are only a little less important than high yield."

TABLE 1.—*The means of certain characters influencing yield*

Variety	Yield per plant, grams	Tillers May 12	Tillers May 21	Tillers May 28	Panicles per plant	Whorls per plant
Markton	6.13±.18	2.39±.06	3.67±.09	4.10±.10	4.00±.08	26.18± .59
Cornellian	5.04±.17	2.08±.16	3.47±.24	3.94±.05	3.61±.08	27.47± .69
Texas Red	4.78±.14	2.76±.11	4.63±.05	4.72±.12	4.17±.10	27.78± .63
Columbia	4.77±.20	2.07±.17	3.33±.13	3.80±.14	3.87±.12	24.77± .82
Minota	4.77±.21	3.45±.14	5.25±.19	6.30±.23	4.12±.14	27.04± .88
Gopher	4.73±.14	2.54±.08	4.23±.15	4.86±.13	3.90±.09	26.49± .85
Kanota	4.68±.13	2.92±.09	4.55±.13	4.93±.13	4.77±.12	27.10± .72
Burt	4.52±.18	2.72±.09	3.99±.13	4.42±.14	4.17±.12	26.51± .78
Iogren	4.31±.16	2.21±.08	3.49±.13	4.43±.19	3.22±.12	23.01± .83
Wayne	4.15±.15	2.39±.08	3.98±.11	4.83±.13	2.94±.14	19.93± .98
Progeny 137	3.96±.12	1.95±.10	3.60±.11	4.00±.13	4.15±.13	26.59± .79
Progeny 105	3.94±.11	2.60±.24	3.71±.07	4.11±.08	4.04±.03	24.61± .70
Progeny 140	3.81±.10	2.24±.07	3.59±.10	4.27±.11	3.57±.07	22.73±1.09
Richland	3.75±.13	2.91±.09	4.19±.08	4.26±.14	4.68±.14	24.78± .62
Iowar	3.71±.15	1.99±.08	3.84±.14	4.30±.14	3.12±.09	19.95± .63
Albion	3.62±.15	1.97±.08	3.48±.12	3.96±.14	3.57±.11	22.02±1.01
Iogold	3.47±.15	2.88±.12	4.80±.17	5.15±.17	3.37±.11	22.26± .76
Fowld's Hull-less	2.95±.09	3.15±.12	5.00±.09	5.60±.06	3.69±.09	19.26± .43
Great Avalanche	2.93±.09	0.93±.05	1.41±.05	1.58±.05	1.33±.04	10.43± .32
Illinois Hull-less	2.33±.15	1.74±.13	3.79±.18	4.79±.21	2.95±.12	18.70± .90

Several investigators have attempted an analysis of yield in various small grains and, in consequence, considerable information has been obtained. Definite contributions to our knowledge of yield have been made by Engledow and Ramiah (4), Waldron (10), Immer and Stevenson (9), Bridgford and Hayes (2), Bonnett and Woodworth (1), and others.

Yield of a variety as used in this paper is considered to be the average weight of seed produced per plant. Yield, as well as the other characters observed, was considered on a plant basis since the plant is genetically the ultimate unit.

Large differences between certain varieties in yield per plant were found. The yield ranged from 6.13 grams for Markton to 2.33 grams for Illinois Hull-less.

YIELD PER PANICLE

The average yield per panicle is an important factor in determining the yielding ability, and hence the value, of an oat variety. Bonnett and Woodworth (1) found that in barley the yield per unit area depended upon the yield per head as well as upon the number of heads, and that varieties having a large number of heads may not be

[3]Reference by number is to "Literature Cited," p. 201.

superior in yield to those producing a smaller number due to differences in the weight of seed produced per head.

The same relations were found to hold in oats. Thus, Kanota and Richland ranked first and second, respectively, among the varieties studied for number of panicles per plant, and seventh and fourteenth

in 20 varieties of oats, arranged in order of yield per plant.

Branches per plant	Yield per panicle, grams	Branches per panicle	Branches per whorl	Whorls per panicle	Percentage sterile spikelets	Percentage of hull	Av. wt. of one seed, grams
86.61±2.17	1.49±.02	21.40±.14	3.29±.02	6.49±.03	13.06±1.85	28.8± .30	0.027
83.35±2.21	1.35±.02	22.79±.18	3.02±.02	7.53±.03	25.12± .90	31.0± .99	0.023
85.89±3.43	1.13±.02	20.38±.18	3.05±.02	6.63±.13	17.98±2.47	28.8± .73	0.022
81.34±3.05	1.16±.03	20.26±.29	3.19±.18	6.28±.01	6.18± .82	27.1± .27	0.023
84.61±2.86	1.11±.02	20.13±.23	3.07±.08	6.57±.04	18.18± .99	30.9± .59	0.024
81.09±1.15	1.18±.02	20.38±.18	3.10±.03	6.55±.07	18.90±1.67	28.7± .32	0.023
75.57±2.25	0.97±.02	15.70±.22	2.74±.02	5.69±.05	3.83± .76	27.6± .84	0.027
78.33±2.61	1.03±.01	18.32±.25	2.89±.03	6.27±.04	9.16±1.59	31.2± .51	0.020
69.61±2.35	1.32±.03	21.80±.22	3.03±.04	7.17±.06	27.58±2.61	30.1± .49	0.023
59.63±2.17	1.37±.06	19.86±.23	2.97±.03	6.70±.05	22.44±1.12	31.7± .74	0.027
82.28±2.31	0.89±.02	18.79±.24	2.95±.09	6.27±.06	12.03±1.40	30.9± .39	0.018
77.34±1.89	1.07±.01	19.92±.35	3.17±.01	6.34±.04	15.70± .52	29.5± .31	0.018
67.36±1.60	1.04±.01	18.58±.17	2.95±.02	6.29±.08	14.22±1.08	30.5± .42	0.019
74.64±1.51	0.95±.01	17.91±.19	2.81±.02	6.19±.06	9.24± .82	32.2±1.03	0.018
63.17±2.28	1.13±.02	19.49±.25	3.09±.03	6.31±.02	9.58±1.58	28.6±1.55	0.019
65.61±2.32	0.95±.02	17.81±.19	2.91±.02	6.07±.06	16.25±1.06	31.4±1.02	0.018
66.00±2.46	0.98±.02	18.99±.21	2.91±.03	6.51±.15	18.24±1.46	32.7± .45	0.018
53.67±1.46	0.90±.01	15.29±.21	2.69±.04	5.79±.02	13.80±1.46	...	0.018
33.88±1.03	2.19±.06	25.20±.37	3.19±.06	7.53±.11	30.25±2.92	46.8± .76	0.030
49.93±2.66	0.74±.01	16.12±.30	2.61±.03	6.18±.06	18.62± .71	...	0.014

for yield per plant. These varieties ranked fifteenth and sixteenth, respectively, in yield per panicle. Hence, low yield per panicle prevented these varieties from giving a high yield per plant, although they produced a large number of panicles.

In 19 out of the 20 varieties studied, the average yield per panicle was found, in general, to increase as the number of panicles increased. (See Fig. 1). In other words, a plant producing two panicles yielded more than twice as much as a one-panicle plant. In certain varieties, the average yield continued to increase with the panicle number up to the limit of panicle production. Other varieties gave an increased average yield up to a certain number of panicles, usually from four to six, and then gave a decreased average yield as the number of panicles increased. Still other varieties increased in average yield up to a certain number of panicles after which the average yield remained stationary for increasing numbers of panicles per plant. One variety, Great Avalanche, seemed to have a tendency exactly opposite to that shown by the majority of varieties with respect to this character. In this variety, the one-panicle plants gave the highest average yield.

The same relationship between yield per head and number of heads per plant has been pointed out by Engledow and Ramiah (4), Bonnett and Woodworth (1), and others in wheat and barley.

TILLERING AND PANICLES

Certain oat varieties show distinct differences in number of tillers, number of panicles, and in the ratio of total number of tillers to number of panicles produced. Engledow and Ramiah (4) found distinct varietal differences for number of tillers and heads produced in wheat

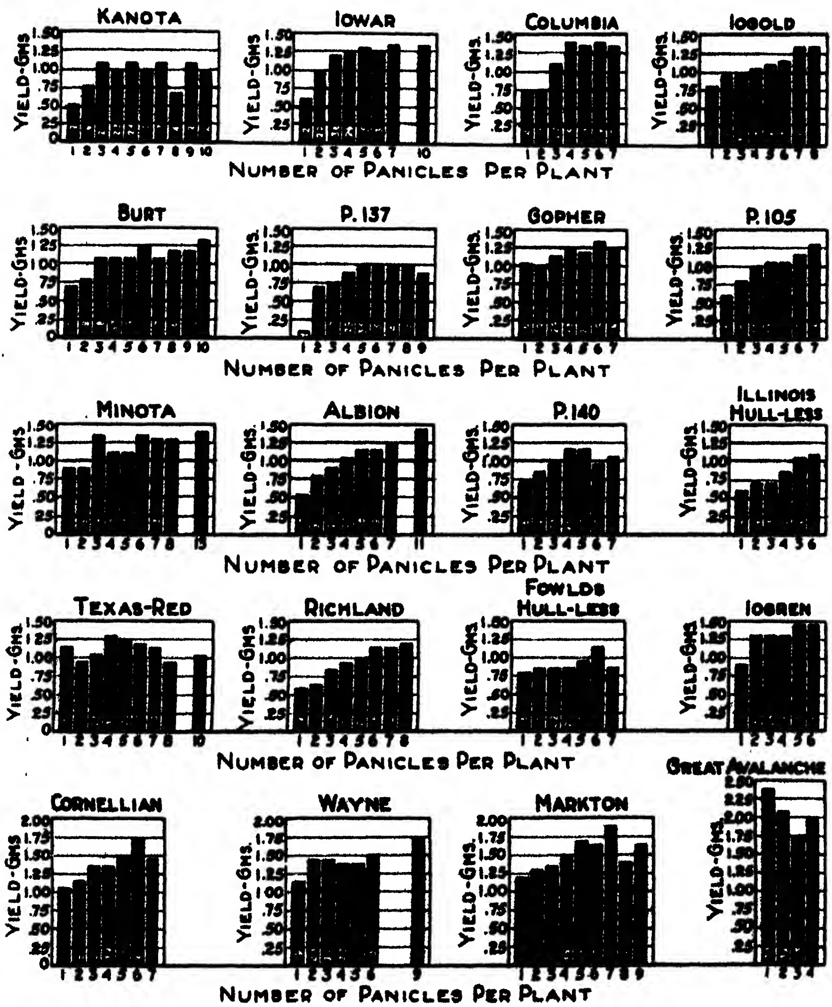

Fig. 1.—Average yield per panicle of plants having different numbers of panicles. The figures within the bars represent the number of plants with the indicated number of panicles.

and pointed out the fact that there is a "critical period" after which new tillers will not form heads. Garber and Quisenberry (7) showed that the number of panicle-bearing culms is an inherited varietal characteristic in oats. Bonnett and Woodworth (1) have shown distinct varietal differences in head number among barley varieties,

and also noticed that the number of heads does not necessarily equal the total number of tillers produced.

Fig. 2 shows graphically the average number of tillers per plant for each variety at four different dates and the average number of panicles at harvest time. The main stem was included in these tiller

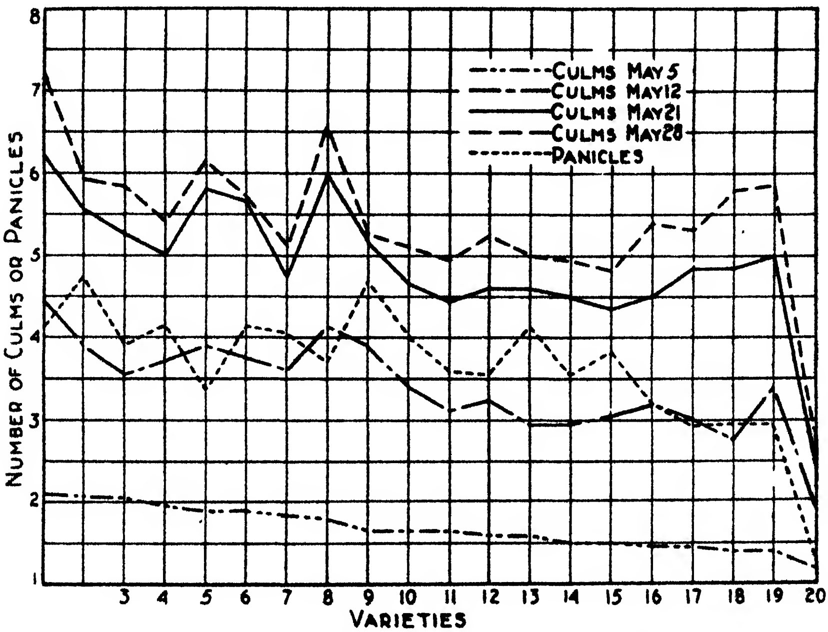

FIG. 2.—Comparison of varieties as to number of culms at four growth stages and as to number of panicles at harvest. Culms include main culm and tillers. The varieties are as follows: 1. Minota; 2. Kanota; 3. Gopher; 4. Burt; 5. Iogold; 6. Texas Red; 7. Progeny 105; 8. Fowlds Hull-less; 9. Richland; 10. Markton; 11. Cornellian; 12. Progeny 140; 13. Progeny 137; 14. Albion; 15. Columbia; 16. Iogren; 17. Iowar; 18. Illinois Hull-less; 19. Wayne; and 20. Great Avalanche.

counts. Some varieties, such as Minota, Fowlds Hull-less, and Wayne, produced a much higher number of tillers as compared with the number of panicles than the majority of varieties. Other varieties, such as Richland, Progeny 137, and Columbia, produced a much lower number of tillers in proportion to the number of panicles than the majority of varieties. Therefore, the number of panicles is not always a reliable measure of tillering ability.

A "critical period" in tiller production, such as that mentioned for wheat by Engledow and Ramiah (4), was found in oats. New tillers continued to arise in most varieties until the latter part of May or even later in some cases, but as is shown by Fig. 2, very few tillers produced after May 12 were able to form panicles. This is indicated by the close proximity of the May 12 tiller line to the panicle line.

There seemed to be a tendency among those varieties giving rise to a large number of tillers to produce a larger number of panicles than those varieties producing a low number of tillers, but some exceptions were noted. On the other hand, there seemed to be no relation

between the number of tillers produced and yield per plant, some high tillering types being high yielding and some low yielding, and low tillering types being either high or low yielding. Hence, it would seem that a large excess of tillers over panicles probably does not benefit the plants from the standpoint of yield.

The varieties studied can be grouped roughly into four classes with respect to rate of tiller production, namely, (a) those producing tillers at a high rate throughout the season, (b) those producing tillers slowly early in the season with an increase in rate later, (c) those producing tillers rapidly early in the season with a decrease in rate the latter part of the season, and (d) those producing tillers at a slow rate throughout the season.

The total number of panicles per plant varied greatly with the variety. Kanota, the highest, had an average of 4.77 panicles per plant, and Great Avalanche, the lowest, an average of only 1.33 panicles per plant.

WHORLS AND BRANCHES

Counts were made of the number of whorls and branches per plant and per panicle, and the number of branches per whorl. The distinct varietal differences found for number of whorls and branches per plant would seem to indicate that these characters are inherited. Whorls, as used in this paper, refer to the clusters of branches borne at the nodes of the rachis, each cluster of branches being a whorl. The tip spikelet was considered to be a whorl. Branches refer to the spikelet-bearing branches borne in whorls at the nodes of the rachis.

Highly significant varietal differences, as shown by the probable error of the difference calculated from the means of the varieties, were found for number of whorls and branches per plant, number of whorls and branches per panicle, and number of branches per whorl.

PERCENTAGE OF STERILE SPIKELETS

Elliott (3) has found that the amount of sterility varies for different varieties of oats when grown under similar conditions, and that sterility occurs without any apparent connection with the halo blight disease.

Huskins (8), in studying sterility, which he terms "blindness" or "blast," concludes that "specific genetic resistance to blindness exists and that differences in degree of blindness are not due to a general physiological correlation with panicle size."

The means of varieties for percentage of sterile spikelets ranged from 3.83 to 30.25. Since the varieties were all grown under the same environment, it would seem that these wide variations must be due to differences in the genetic constitution of the varieties concerned.

PERCENTAGE OF HULL AND AVERAGE WEIGHT OF SEED

In this section, two of the factors concerned with the grain itself will be considered. These factors, per cent of hull and average weight of seed, were the only ones, except yield, dealing directly with the grain upon which data were obtained in this study.

The means of varieties for per cent of hull ranged from 27.1 in Columbia to 46.8 in Great Avalanche.

Large varietal differences considered to be significant were found for average weight of seed. Bonnett and Woodworth (1) found distinct varietal differences for this character in barley, and the same would be expected to hold for oats. The average weight of one seed was calculated from the weight of 1,000 seeds. Hence, the probable errors could not be calculated, and the significance of the differences could not be determined statistically. However, the differences seemed to be much larger than would be expected by chance, especially since the varieties were grown under the same environmental conditions

CORRELATIONS

In order to determine the relations existing between yield and the yield components, correlations were calculated between yield per plant and all other characters upon which data were taken. These correlations were calculated from the means of the varieties. Correlations were also calculated between the different yield components themselves.

The number of varieties used in this study was so small, being only 20, that correlation coefficients may give unreliable results. Fisher (5) states that "with small samples the value of r is often very different from the true value, P, and the factor $1 - r^2$ correspondingly in error; in addition, the distribution of r is far from normal, so that tests of significance based on the above formula (standard error) are often very deceptive."

For these reasons, the relations between characters were studied by two different methods, namely, "correlation diagrams," and Pearson's coefficient (r). Diagrams similar to those shown in Fig. 3 for yield per plant were drawn for all characters, but are not included in this paper due to lack of space. The correlation coefficients obtained between all characters are given in Table 2.

Since the varieties were ranked in order of yield per plant in all diagrams in Fig. 3, any characters showing a positive correlation with yield gave the same type of figure as that for yield. Negative correlations are indicated by a tendency of the figure for the character under consideration to slope in the opposite direction from that for yield. Thus, the varieties showing the longest bars in the yield figure would be represented by the shortest bars in the figure for the other characters concerned. The degree of slope and the regularity of the diagram indicate roughly the amount of association between yield per plant and the other characters under consideration.

Yield per plant shows a high correlation with only two characters, *viz.*, number of whorls per plant and number of branches per plant. The coefficients obtained were as follows: (r) = .723 ± .072 and .816 ± .051, respectively. Small but significant correlations were also found between yield per plant and two other characters, *viz.*, number of panicles per plant and number of branches per whorl. Correlations were considered significant statistically if they were 3.2 or more times the probable error.

TABLE 2.—*Correlations between yield per plant and certain yield components and between the components themselves, calculated from the means of oat varieties.*

	Yield per plant	Tillers per plant, May 21	Panicles per plant	Whorls per plant	Branches per plant	Yield per panicle	Branches per panicle	Branches per whorl	Whorls per panicle	Per cent sterile spikelets	Per cent of hull
Yield per plant.........											
Tillers per plant, May 21	.23±.143										
Panicles per plant.......	.49±.115	.68±.083									
Whorls per plant.......	.72±.072	.56±.104	.89±.033								
Branches per plant......	.82±.051	.43±.122	.81±.054	.97±.009							
Yield per panicle........	.17±.146	—.74±.068	—.70±.078	—.51±.112	—.35±.133						
Branches per panicle.....	.31±.137	—.62±.094	—.50±.113	—.16±.148	.02±.149	.89±.033					
Branches per whorl......	.48±.116	—.34±.134	—.13±.149	.01±.151	.33±.134	.66±.085	.87±.038				
Whorls per panicle......	.12±.149	—.57±.103	—.61±.095	—.24±.143	—.14±.149	.78±.060	.94±.018	.44± 124			
Per cent sterile spikelets	—.19±.146	—.39±.128	—.69±.079	—.44±.122	—.39±.128	.58±.101	.65±.088	.23±.143	.85±.042		
Per cent of hull.........	.36±.132	—.42±.125	—.12±.149	.04±.149	.17±.148	.59±.100	.61±.080	.61±.097	.52±.110	.22±.144	
Average weight one seed.	.11±.149	—.26±.142	—.16±.148	—.06±.149	.03±.149	.91±.206	.67±.083	.57±.103	.49±.114	.29±.139	.45±.122

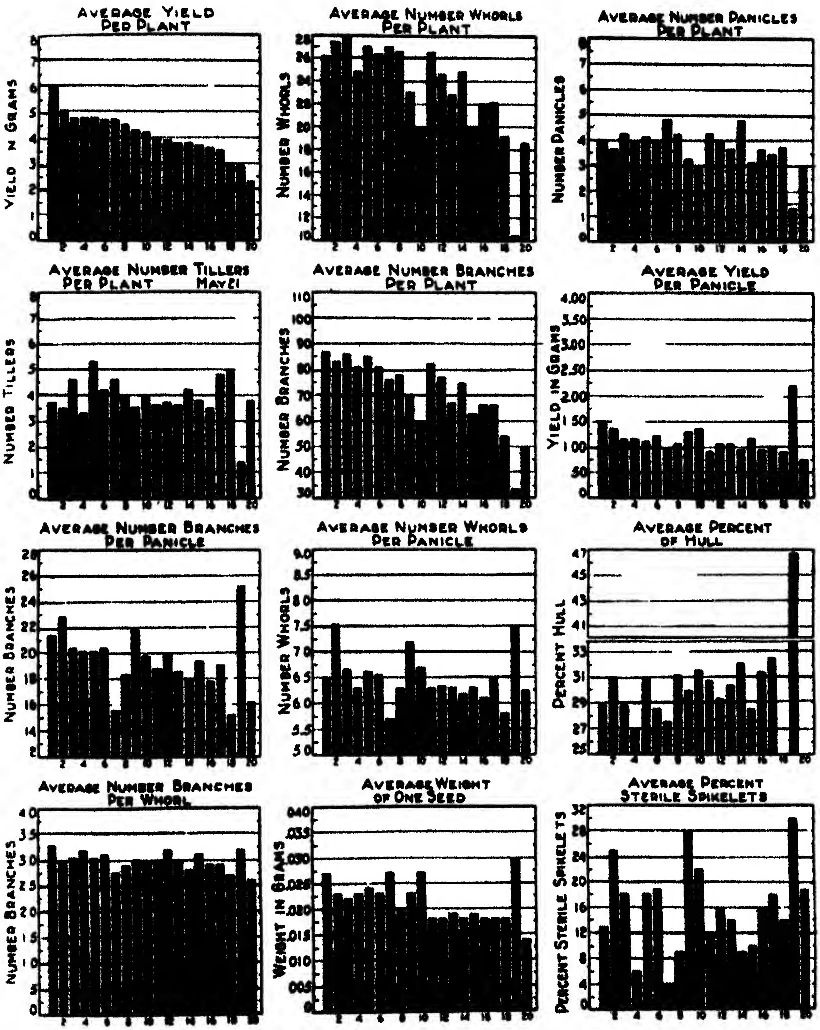

FIG. 3.—Bar diagrams showing relations between yield per plant and other characters for 20 oat varieties. The numbers below the bars designate the varieties, which are as follows: 1. Markton; 2. Cornellian; 3. Texas Red; 4. Columbia; 5. Minota; 6. Gopher; 7. Kanota; 8. Burt; 9. Iogren; 10. Wayne; 11. Progeny 137; 12. Progeny 105; 13. Progeny 140; 14. Richland; 15. Iowar; 16. Albion; 17. Iogold; 18. Fowlds Hull-less; 19. Great Avalanche; and 20. Illinois Hull-less.

Significant positive correlations were also found between the following characters:

1. Tillers per plant and:	(a) panicles per plant
	(b) whorls per plant
2. Panicles per plant and:	(a) whorls per plant
	(b) branches per plant

3. Whorls per plant and:	(a) branches per plant
4. Yield per panicle and:	(a) branches per panicle (b) branches per whorl (c) whorls per panicle (d) percent of sterile spikelets (e) percent of hull (f) average weight of seed
5. Branches per panicle and:	(a) branches per whorl (b) whorls per panicle (c) percent sterile spikelets (d) percent of hull (e) average weight of seed
6. Branches per whorl and:	(a) percent of hull (b) average weight of seed
7. Whorls per panicle and:	(a) percent of sterile spikelets (b) percent of hull

Significant negative correlations were found between the following characters:

1. Tillers per plant and:	(a) yield per panicle (b) branches per panicle (c) whorls per panicle
2. Panicles per plant and:	(a) yield per panicle (b) branches per panicle (c) whorls per panicle (d) percent of sterile spikelets
3. Whorls per plant and:	(a) yield per panicle

DISCUSSION

It is believed that the relations found among the characters studied are genetic in nature. Two reasons for this belief may be cited as follows: (a) The growth conditions for all varieties were the same, and (b) the correlation coefficients were calculated from the means of the respective varieties. Therefore, it would be expected that characters closely correlated would exhibit a tendency to be inherited together. Cross breeding experiments are needed to check the relationships found, and this work is now in progress.

From the plant breeding standpoint, high correlation coefficients, either positive or negative, obtained from the varietal means, may be desirable or undesirable, depending upon the characters being considered. Between such characters as number of panicles per plant and yield per panicle, a high positive correlation would be desirable. In this case, a high correlation would indicate that some varieties now

in existence are high for both characters, and hence this particular combination would not have to be produced by crossing.

A high negative correlation between the above-mentioned characters would be undesirable as it would indicate that there are likely no varieties in existence in which very high values for both characters are combined. Also, the chances of producing such a type by crossing would be rather small since high in one character would tend to be inherited with low in the other.

For certain characters, such as percent of sterile spikelets and number of panicles per plant, a high negative correlation would be desirable as it would indicate that some varieties now existent are low in sterility and high in number of panicles. A high positive correlation between these characters would be undesirable.

A correlation of zero may be more desirable in certain cases as it would indicate that the two characters being considered were inherited independently. Therefore, no difficulty, other than the question of numbers would be encountered in combining them into one strain by crossing.

SUMMARY

A yield analysis of 20 varieties of oats was made. Data were taken on about 100 individual plants of each variety for 12 characters influencing yield. These characters were tillers per plant, panicles per plant, whorls per plant, branches per plant, yield per plant, yield per panicle, whorls per panicle, branches per panicle, branches per whorl, percent of sterile spikelets, percent of hull, and average seed weight. All characters were considered on a plant or panicle basis.

An attempt was made to eliminate, in so far as possible, all environmental differences by the method of planting. The seeds were space planted and each variety was replicated 15 times, the replicates being scattered systematically throughout the plat.

The means of varieties were used as a basis for all comparisons. Significant varietal differences were found for all characters upon which data were taken.

Correlation diagrams and correlation coefficients (Pearson's r) were used in studying the relationships between yield per plant and the yield components, and between the components themselves. The correlations were calculated from the means of varieties.

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MOVEMENT OF FERTILIZERS IN CARRINGTON LOAM[1]

OLIVER E. OVERSETH[2]

Many experiments have been conducted to determine the toxicity of certain fertilizer salts but only a limited amount of work has been reported on the movement of fertilizer salts in the soil and practically nothing on the actual measurement of the rate of movement of these salts. It has been the purpose of the experiments described in the following pages to attempt to measure the movement of nitrogen, phosphorus, and potassium in a typical Carrington loam with moisture conditions maintained at the optimum. A study was also made of the movement of these plant foods out of various complete and incomplete fertilizers after varying periods of time in the soil.

Collison and Walker (4)[3] showed by lysimeter tests that there was a large loss of nitrates from soil compared with that of phosphorus and potassium. Harper (9) found that adding water to Carrington loam in an amount equivalent to 1 inch of rainfall had very little effect on the leaching of nitrates or other plant foods, but a rain of 2.56 inches caused a considerable movement of nitrates. Smith and Harper (11) concluded that there was no chance for a loss of nitrates in Carrington loam during plant growth. They found that 8 weeks after applications of 100 or 200 pounds of a 2–12–2 fertilizer nearly all of the nitrogen added was taken up by the corn.

Investigators have generally concluded that the movement of phosphorus in the soil is extremely slow. In sandy soils which are irrigated, the movement, and perhaps the loss of phosphorus, may be significant, but in loams or clays practically no phosphorus can be found in the drainage waters. Midgley (10) found that with sodium phosphate, ammonium phosphate, and potassium phosphate, 88, 3.3, and 3.2%, respectively, of the phosphates were leached out. Bear and Salter (2) reported that when phosphoric acid was applied to the soil in excess of the needs of the crop there was no loss in the drainage water, but that the phosphorus was fixed in the surface 6 2/3 inches of soil. Harper (9) noted that some phosphorus was transported 2 to 4 inches below the surface of the soil. During a season of high rainfall, however, he found that the phosphorus in 16%

[1]Contribution from the Department of Farm Crops and Soils, Iowa State College, Ames, Iowa. Part of a thesis submitted in partial fulfillment of the requirements for the degree doctor of philosophy at the Iowa State College. Received for publication July 21, 1932.

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[3]Reference by number is to "Literature Cited," p. 216.

superphosphate was not leached to a greater depth than 4½ inches in a Carrington loam. Under normal conditions there was very little movement beyond the surface inch.

Van Alstine (12) concluded that when phosphorus is used as a fertilizer, it remains where it is placed until removed by crops or by other agencies, such as erosion by wind or water. Crawley and Cody (6) concluded that phosphoric acid is very quickly and firmly fixed by all soils. Crawley (5) conducted an experiment in which he used over 7 tons of double superphosphate on an acre of Hawaiian soil which was immediately irrigated. The first inch of soil retained over 50%, the 3-inch depth over 90%, and the 6-inch depth all the phosphorus added.

Ellett and Hill (7) reported that soil bases which fix phosphoric acid include iron, aluminum, lime, and magnesium. The hydroxides of iron and alumina fixed 60 to 70% of the water-soluble phosphates into insoluble and relatively unavailable forms. Hall and Vogel (8) concluded that in soils having the most total iron there was the most reversion.

Potassium is also fixed in certain soils and the movement, although more rapid than that of phosphorus, is quite slow. Crawley and Cody (6) noted that heavy rains leached potassium salts from the surface soil before the potassium was fixed, but after fixation had occurred leaching removed the potassium very slowly.

EXPERIMENTAL

The investigations reported here have been divided into two parts, one, a study of the movement of soluble plant foods out of fertilizer samples placed in Carrington loam, and the other a study of the plant food movement in the soil. It was also considered important to determine what part of this movement took place during germination and early growth of plants. No attempt has been made to study the upward movement and only a small amount of work has been done on the lateral movement of the soluble salts.

The fertilizers used in the first two experiments were 16% superphosphate and a complete fertilizer, 3–12–3. In the third experiment, various fertilizers were tested. By using these various analyses the movement of any single ingredient, and its effect on the movement of other ingredients, could be more carefully studied. The influence of different rates of application was also studied. In all cases the fertilizers were applied in the hill and the amounts added per hill were figured on the acre basis for corn checked 42 inches by 42 inches.

The study was carried out in the greenhouse where accurate control of temperature, moisture, and other factors was possible. All treatments were made in duplicate. The fertilizers were weighed out in double cheesecloth bags which were placed carefully in the soil. Thus it was possible to recover fully all the unleached portion. The small mechanical losses in placement were subtracted from the original weight when the recovered fertilizer was again weighed for the determination of the soluble material leached out of the sample.

MOVEMENT OF FERTILIZER SALTS IN CARRINGTON LOAM AT VARYING INTERVALS FROM 1 TO 12 WEEKS

In 1922, Coe (3) conducted an experiment in the greenhouse in which tests were made in boxes of the influence of two different systems of watering on the movement of the soluble fertilizer salts in the soil. The soils were all maintained at the optimum moisture content. In the boxes labeled "below" the distilled water was supplied through a tube that led to the bottoms of the boxes and the water diffused upward into the soil through a sand layer. In the boxes labeled "above" the water was added slowly to the surface.

The two fertilizers used were superphosphate and a complete fertilizer, 3-12-3 made up of ammonium sulfate, superphosphate, and muriate of potash. The superphosphate was applied at the rate of 300 pounds per acre and the 3-12-3 at the rate of 200 pounds per acre. The applications of the fertilizers were made "above," "both sides," "at the rear," and "below" in relation to the seed. At intervals of 1, 2, 3, 4, 6, 8, 10, and 12 weeks Coe took samples of soil and removed the fertilizer samples. Due to the small amount of fertilizer used in the first place and to leaching of the samples, only small quantities of the original fertilizers were recovered.

In the work reported here the samples of the two fertilizers taken at the different dates were composited, regardless of the position in the soil in relation to the seed, but according to the two methods of watering. These composite samples were analyzed and the results of the analyses of the superphosphate samples are reported in Table 1.

The original superphosphate sample contained 4.434% of water-soluble phosphorus, 1.415% of neutral ammonium citrate-soluble phosphorus, and 0.677% of citrate-insoluble phosphorus. The total phosphorus content was 6.526%

TABLE 1.—*Water-soluble, ammonium citrate-soluble, citrate-insoluble, and total phosphorus content of superphosphate.*

Weeks in soil	Water-soluble phosphorus		Ammonium citrate-soluble phosphorus		Citrate-insoluble phosphorus %	Total phosphorus in sample %
	% in sample	% of total	% in sample	% of total		
0*	4.434	67.9	1.415	21.6	0.677	6.526
1	0.381	9.1	3.100	74.1	0.702	4.183
2	0.391	7.8	3.875	77.9	0.705	4.971
3	0.377	7.6	3.868	78.6	0.674	4.919
4	0.367	7.6	3.780	78.2	0.683	4.831
6	0.377	8.0	2.640	77.9	0.658	4.674
8	0.350	8.8	2.898	73.1	0.717	3.965
10	0.286	7.4	2.750	71.0	0.836	3.871
12	0.273	7.3	2.648	71.4	0.789	3.711

*Analysis of original sample

After 1 week in the soil the superphosphate sample contained only 0.381% of water-soluble phosphorus. Practically all the water-soluble phosphorus had leached out of the sample or had changed in

form during the 7 days' contact with the soil. In the original sample, nearly 68% of the total phosphorus was water-soluble and after 1 week in the soil only 9.1% was water-soluble. After 2 weeks, 7.8% of the phosphorus was water-soluble, and from the third to the sixth weeks the loss was not increased. However, there was a further significant loss after the tenth week and a slight loss after the twelfth week in the soil.

Neutral ammonium citrate-soluble phosphorus, recognized by Bear (1) as reverted or dicalcium phosphate, increased from 1.415% in the original sample to 3.100% after the first week. This was further increased to 3.875% at the end of 2 weeks. In the original sample 21.6% of the total phosphorus was citrate-soluble and this was increased to 74.1% after contact with the soil for 1 week. There was a further increase to 77.9% after 2 weeks. After 4 weeks there was a decrease, and further considerable decreases after 8, 10, and 12 weeks. It seems possible that the citrate-soluble phosphorus was gradually changing to citrate-insoluble, especially during the last 2 weeks of the experiment when the samples showed the largest amount of citrate-insoluble phosphorus at any time during the experiment.

A study of these data shows a very rapid loss of phosphorus from the fertilizer, especially during the first week. The original sample contained 6.526% phosphorus and this was reduced to 4.183% after 1 week. It is assumed that the readily soluble phosphorus, and perhaps other soluble material, moved out of the fertilizer sample.

Table 2 shows the results of the analyses of the samples of the complete fertilizer, 3-12-3. It was evident that the same reactions took place and that the outward movement of phosphorus was similar to that occurring with the superphosphate. This was to be expected as the phosphorus in 3-12-3 was in the superphosphate form. Apparently the sulfate of ammonia and muriate of potash had no effect on the movement of phosphorus out of the fertilizer tested in this work.

TABLE 2.—*Water-soluble, ammonium citrate-soluble, citrate-insoluble, and total phosphorus content of complete fertilizer 3-12-3.*

Weeks in soil	Water-soluble phosphorus		Ammonium citrate-soluble phosphorus		Citrate-insoluble phosphorus %	Total phosphorus in sample %
	% in sample	% of total	% in sample	% of total		
0*.......	3.855	67.2	0.657	11.4	0.612	5.736
1........	0.290	7.9	2.891	79.0	0.478	3.659
2........	0.283	7.5	3.053	80.6	0.523	3.788
3........	0.256	7.1	2.803	78.0	0.535	3.594
4........	0.269	7.8	2.710	79.0	0.449	3.427
6........	0.246	7.5	2.507	77.0	0.512	3.265
8........	0.269	7.8	2.684	78.7	0.455	3.409
10........	0.202	5.7	2.493	70.9	0.821	3.516
12........	0.249	7.1	2.345	67.1	0.899	3.493

*Analysis of original sample.

The question arises, in what form does the phosphorus in superphosphate go into solution and move out of the fertilizer sample placed in the soil? From the data presented, it is concluded that a change took place in the sample. The decided decrease in water-soluble phosphorus and the very noticeable increase in citrate-soluble phosphorus after 1 week in the soil seems to indicate a change from the monocalcium phosphate to the dicalcium form. There was probably also a further change to the tricalcium form.

The amount of citrate-insoluble phosphorus, which is often termed tricalcium phosphate, remained fairly constant through the 8-week period and then increased both with the superphosphate and with the complete fertilizer samples. However, this increase was somewhat more pronounced in the case of the complete fertilizer. The formation of tricalcium phosphate in the fertilizer sample is apparently a slow process and did not take place to any extent until after all the monocalcium phosphate had either moved out or reverted to dicalcium phosphate.

The movement of nitrogen out of the complete fertilizer was quite rapid. The original sample contained 2.47% nitrogen in the form of ammonium sulfate. After 1 week in the soil, the total nitrogen was reduced to 0.168%. The loss was then gradual to the end of the experiment when the sample showed only 0.084% nitrogen.

The movement of potassium in the 3-12-3 was also quite rapid. The original sample contained 2.926% potassium and after the first week in the soil only 0.0672% remained. This amount remained fairly constant until the end of the experiment.

MOVEMENT OF FERTILIZER SALTS IN CARRINGTON LOAM AT VARYING INTERVALS FROM 1 DAY TO 2 WEEKS

The rapid movement of soluble salts out of the fertilizers used in the preceding work during the first 7 days indicated the desirability of testing samples taken out of the soil after 1, 3, 7, and 14 days. Accordingly, studies were made in the same boxes and the soil was watered from below or above as previously described. The same fertilizers were applied at the same rates. However, to facilitate the removal of the fertilizer, the samples were placed in cheesecloth bags 2 by 5 inches in size. The first samples were removed from the soil the following day, allowing the fertilizer to remain in position 24 hours. There was no watering during this period. The remaining samples were taken after 3, 7, and 14 days in the soil. Analyses were made as before and the results appear in Tables 3 and 4.

From the data presented in Table 3 it is obvious that a significant movement of phosphorus took place during the first day the superphosphate sample was in the soil. The total phosphorus in the superphosphate was 7.160% and after 1 day in the soil it was reduced to 6.669 and 6.862% in the soils watered from below and above, respectively. This slight reduction in phosphorus content was due entirely to water movement within the soil as no water was added to the soils the first 2 days of this experiment. Analyses of the fertilizer samples taken after 3 days in the soil showed further losses of

phosphorus which were to be expected as the watering started at the beginning of the third day. The original sample contained 53.06% of the total phosphorus in the water-soluble form. After the first day this was reduced to 45.85 and 49.11% in the two tests. The movement of the water-soluble phosphorus was more pronounced at the

TABLE 3.—*Water-soluble, ammonium citrate-soluble, citrate-insoluble, and total phosphorus content of superphosphate.*

Days in soil	Water-soluble phosphorus		Ammonium citrate-soluble phosphorus		Citrate-insoluble phosphorus %	Total phosphorus in sample %
	% in sample	% of total	% in sample	% of total		
			Watered from Below			
0*	3.799	53.06	3.060	42.73	0.299	7.160
1	3.058	45.85	3.340	50.00	0.271	6.669
3	1.623	28.41	3.628	63.50	0.461	5.713
7	1.473	25.92	3.804	66.93	0.406	5.683
14	0.457	9.54	3.948	82.44	0.383	4.789
			Watered from Above			
0*	3.799	53.06	3.060	42.73	0.299	7.160
1	2.370	49.11	3.171	46.21	0.321	6.862
3	2.690	41.62	3.441	53.24	0.332	6.463
7	1.169	22.07	3.729	70.41	0.399	5.296
14	0.887	16.80	4.061	76.89	0.334	5.281

*Analysis of original sample.

end of the third day when only 28.41% of the total phosphorus in the soil watered from below and 41.62% of that in the soil watered from above were found in the samples. At the end of the experiment 9.54% of the total phosphorus in the sample in the compartment watered from below and 16.80% in the compartment watered from above remained in the water-soluble form.

The phosphorus that remained in the sample as citrate-soluble phosphorus steadily increased in amount, as noted above. The change and increase in dicalcium phosphate was gradual, as shown by an increase from 3.060% in the original sample to 3.340% and 3.171% after the first day in the soils watered from below and above, respectively. There was a further increase after the third day to 3.628% in the soil watered from below, while in the soil watered from above there was an increase to 3.441%.

The original sample of superphosphate contained 42.73% of its phosphorus as the dicalcium phosphate or the neutral ammonium citrate-soluble phosphate. After 1 day in the soil, 50% of the total phosphorus in the sample in the compartments watered from below was found to be in the dicalcium form. After 3 days this was increased to 63.50% and at the end of the experiment it had increased to 82.44%. These results are quite similar to those presented above.

The movement of phosphorus out of the complete fertilizer, 3-12-3, as shown by data in Table 4, was much the same as with the superphosphate. The original sample contained 3.134% water-soluble

phosphorus, which was 50% of the total phosphorus in the sample. After 1 day in the soil this was reduced to 2.062% of the sample, or 38.57% of the total phosphorus. After the third day the fertilizer in the soils watered from below and from above showed further decreases in water-soluble phosphorus. In the soil watered from below there was a decrease to 20.60% of the total phosphorus and in that watered from above to 18.92%. At the end of the first week with the two types of watering about the same amount of water-soluble phosphorus was removed from the fertilizer samples, leaving 12.46% and 15.04% in the soils watered from below and above, respectively. At the end of the experiment about the same amounts of water-soluble phosphorus, namely, 10.80 and 10.26% of the total phosphorus, remained in the fertilizers under the two systems of watering.

TABLE 4.—*Water-soluble, ammonium citrate-soluble, citrate-insoluble, and total phosphorus content of complete fertilizer, 3–12–3.*

Days in soil	Water-soluble phosphorus		Ammonium citrate-soluble phosphorus		Citrate-insoluble phosphorus %	Total phosphorus in sample %
	% in sample	% of total	% in sample	% of total		
			Watered from Below			
0*.......	3.134	50.00	2.933	46.04	0.321	6.370
1........	2.062	38.57	2.970	53.68	0.315	5.346
3........	0.830	20.60	2.845	70.63	0.352	4.028
7........	0.507	12.46	3.121	76.74	0.338	4.067
14........	0.417	10.80	3.134	81.06	0.316	3.866
			Watered from Above			
0*.......	3.134	50.00	2.933	46.04	0.321	6.370
1........	1.676	33.96	2.927	59.31	0.332	4.935
3	0.780	18.92	3.002	72.84	0.338	4.121
7........	0.580	15.04	2.933	76.08	0.342	3.855
14........	0.404	10.26	3.190	81.04	0.341	3.936

*Analysis of original sample.

The dicalcium phosphate changed from 2.933% in the original sample of the complete fertilizer to 2.970 and 2.927% after the first day in the soil. The increase in percentage of the total was from 46.04 to 53.68 in the fertilizers taken from the soils watered from below. The increase was greater in the fertilizer in the soils watered from above, 59.31% dicalcium phosphate appearing in this case at the end of the first day in the soil.

In the soils watered from below there was an increase to 70.63% dicalcium phosphate in the fertilizers after 3 days, 76.74% after 1 week, and 81.06% after 2 weeks. In the soils watered from above, increases to 72.84% after 3 days, 76.08% after 1 week, and to 81.04% after 2 weeks, were found.

The total amount of phosphorus in the complete fertilizer decreased rapidly the first day. This was accounted for by the movement of water-soluble phosphorus out of the fertilizer. The decrease

in total phosphorus was less rapid after the third day and from that time on the movement was quite gradual. The amount of citrate-insoluble phosphorus remained fairly constant during the experiment. Two weeks in the soil did not change much of the phosphorus to the tricalcium form and most of it was changed to the dicalcium phosphate form.

MOVEMENT OF FERTILIZER SALTS IN CARRINGTON LOAM AT VARYING INTERVALS FROM 3 TO 21 DAYS

Approximately 4 kilograms of Carrington loam were placed in 1-gallon pots and distilled water added to bring the moisture content up to the optimum. The moisture was maintained at 24%. Five complete fertilizers, four of which were home-mixed in the laboratory using ammonium sulfate, superphosphate, and muriate of potash, and one, a commercial product sold under the trade name Nitrophoska, 15–30–15, and three single ingredient fertilizers mixed with sand to make the same weight of fertilizer were added to the soils.

A comparison of 4–16–4 with 0–16–0 was planned to show the effect of 4% nitrogen and 4% potash on the movement of phosphorus out of the 16% phosphate. Likewise, a comparison of 4–16–4 with 4–0–0 was made to show the effect of phosphorus and potassium on the movement of nitrogen, and a comparison of 4–16–4 with 0–0–4 to show the effect of nitrogen and phosphorus on the movement of potassium. A comparison of 2–8–8 and an 8–2–8 was made to indicate the effect of an increased amount of nitrogen on the movement of a decreased amount of phosphorus with the potassium content kept constant. Conversely, the effect of a decreased amount of phosphorus should indicate the effect on the movement of an increased amount of nitrogen. Similarly, comparisons of 2–8–8 and 8–8–2 and of 8–2–8 and 8–8–2 were made to show other effects of the different fertilizer salts on the movement of the various constituents.

The loss of fertilizer material through unavoidable sifting out of the cheesecloth bags during the process of placing the fertilizer in the soil was deducted from the total amount of fertilizer placed in the bags.

After removal from the soil, the fertilizer samples were air dried and weighed. The difference in weight of these samples and the original 25.5 grams, minus that lost through handling, represents the loss due to the action of water. The losses in weight of the various fertilizers used in the experiments are shown in Table 5. Examination of these data shows that the greatest loss in weight or movement of soluble material took place during the first 2 days after placing the fertilizer in the soil. This was especially true with the more soluble fertilizer materials, such as sulfate of ammonia and muriate of potash. The data show that the loss of weight of the 4–0–0 and 0–0–4 after the first 2 days in the soil accounted for nearly all of the fertilizer material added to the sand to make the weights used of these materials. On the other hand, slowly soluble materials, like superphosphate in the 0–16–0, were not lost to such a large extent. The 8–2–8 lost nearly half of its weight during the 4-day period and then showed a slight additional loss up to 21 days. The loss of ammonium sulfate in 8–8–2 was greater than the loss of muriate of potash in 2–

8–8, due to a greater volume of sulfate added to make the 8–8–2 than was required of the muriate of potash to make the 2–8–8.

TABLE 5.—*Loss in weight of fertilizers in grams.**

Fertilizer analysis	Days in soil						
	2	4	6	8	10	14	21
4–16–4 . . .	6.537	6.840	7.045	7.472	7.312	7.282	7.432
4–0–0. .	4.415	4.397	4.352	4.775	5.277	5.197	5.307
0–16–0. .	4.115	4.545	4.850	4.825	4.947	5.140	4.965
0–0–4. .	2.008	1.743	2.168	2.073	2.053	2.235	2.205
2–8–8.	5.814	6.549	7.034	7.216	6.586	6.564	6.881
8–2–8. . . .	10.113	11.318	11.248	11.625	11.138	12.700	12.255
8–8–2. . . .	7.693	8.553	9.438	9.585	9.963	10.448	10.578

*Original amount 25.5 grams.

From the results of the analyses of the phosphorus content of the fertilizer samples presented in Table 6 it is obvious that only a part of the phosphorus moved out of the fertilizers during the experiments. The movement of phosphorus was more pronounced during the first 2 days and apparently reached practically an equilibrium after the tenth day in some cases. There were further losses in some of the fertilizers, but these losses were not as great as those that occurred during the first part of the experiment.

TABLE 6.—*Percentage phosphorus content of fertilizers.*

Fertilizer analysis	Days in soil						
	2	4	6	8	10	14	21
4–16–4. . . .	6.020	5.167	5.016	4.662	4.460	4.258	4.174
0–16–0. . . .	5.100	4.747	4.661	4.628	4.275	4.539	3.534
2–8–8.	1.675	1.978	2.070	2.323	1.994	1.767	1.935
8–2–8.	0.538	0.549	0.562	0.604	0.589	0.696	0.673
8–8–2.	2.342	2.550	2.196	2.213	1.952	1.935	2.092

At the close of the 2-day period there was less phosphorus in the 16% superphosphate than in the 4–16–4, indicating a greater outward movement in the case of the superphosphate. A similar relationship between these two fertilizers was noted during the entire duration of the experiment and was probably due to the fact that the sulfate of ammonia and muriate of potash, being more soluble than superphosphate, dissolved and leached out, leaving a higher percentage of phosphorus.

There was a greater movement of phosphorus out of the 2–8–8 than out of the 8–8–2. This greater movement was noted throughout the study and especially during the first part of the experiment. Comparing the movement of phosphorus in these two fertilizers with different amounts of nitrogen and potassium, the phosphorus content being constant, it appears that an increased nitrogen content and a decreased potassium content influenced the movement of phosphorus.

The movement of phosphorus was the least when the fertilizer contained the largest percentage of nitrogen. During the latter part of the experiment, the differences were less noticeable.

These data indicate in general that potash apparently had little or no effect on the movement of phosphorus, while the nitrogen used in these experiments supplied in the form of sulfate of ammonia tended to bring about a slower movement of phosphorus. This slowing up of the phosphorus movement was perhaps due to the formation of ammonium phosphate that is less soluble in cold water than monocalcium phosphate.

Table 7 gives the results of the analyses of the fertilizer samples for nitrogen content. In all cases there was a considerable decrease in the amount of nitrogen in the fertilizer at the end of the 4-day period. Sulfate of ammonia mixed with quartz sand to make a 4–0–0 fertilizer lost nearly all its nitrogen during the 6-day period and contained only a trace of nitrogen at the end of the experiment. The nitrogen in the 4–16–4 leached out of the fertilizer at a much slower rate. At the end of the 2-day period, the 4–16–4 fertilizer still contained an average of 1.544% nitrogen and at the end of the 6-day period an average of 1.036% nitrogen.

TABLE 7.—*Percentage nitrogen content of fertilizers.*

Fertilizer analysis	Days in soil						
	2	4	6	8	10	14	21
4–16–4.	1.544	1.128	1.036	0.704	0.599	0.437	0.381
4–0–0. .	0.077	0.056	0.049	0.021	0.021	0.010	0.007
2–8–8.	0.409	0.374	0.338	0.317	0.324	0.246	0.142
8–2–8.	2.002	1.008	0.874	0.685	0.528	0.444	0.423
8–8–2.	2.093	2.396	2.065	1.594	0.944	0.500	0.289

When the fertilizers 8–2–8 and 8–8–2 are compared it is evident that throughout the experiment there was a greater movement of nitrogen from the 8–2–8 than from 8–8–2. This tends to confirm the suggestion that superphosphate reduced the movement of sulfate of ammonia. It has been noted earlier that the movement of phosphorus was hindered by the presence of sulfate of ammonia. Increasing the phosphorus and decreasing the potassium quite noticeably delayed the outward movement of nitrogen. This action was more pronounced during the first 10 days of the experiment.

The results of the analyses of the various fertilizers for the potassium content are given in Table 8. It is evident here that the movement of potassium when applied as muriate of potash in combination with sulfate of ammonia and superphosphate was not as great as the movement of sulfate of ammonia used alone or in combination with superphosphate and muriate of potash. There was very little potassium in the 0–0–4 after the 8-day period and only a trace after the 10-day period.

TABLE 8.—*Percentage potassium content of fertilizers.*

Fertilizer analysis	Days in soil						
	2	4	6	8	10	14	21
4–16–4.....	2.341	2.255	2.168	1.267	1.499	1.028	0.296
0–0–4......	0.026	0.022	0.033	0.023	0.010	Trace	Trace
2–8–8.....	7.513	6.106	3.627	2.845	2.472	1.890	1.407
8–2–8.....	8.180	8.045	7.480	7.125	6.955	5.475	4.815
8–8–2....	1.000	0.917	0.283	0.240	0.186	0.188	0.156

A comparison of 2–8–8 and 8–2–8 with the potash maintained at 8%, the nitrogen content increased, and the phosphorus content decreased shows that nitrogen and phosphorus had a marked effect on the movement of potassium. At the close of the first 2-day period there was little difference and at the conclusion of the 4-day period the increased phosphorus and decreased nitrogen in the fertilizer caused a greater outward movement of potassium. This was true throughout the experiment, the difference becoming greater the longer the fertilizer remained in the soil. No doubt much of these great differences was due in part to the large amount of nitrogen in the 8–2–8. As the nitrogen dissolved out more rapidly than did the potassium, there was an increase in the percentage of potassium in the fertilizer.

Soil samples taken at the sides and below the fertilizer were analyzed for phosphorus content. The results are given in Table 9. From these data it is evident that lateral movement of phosphorus was usually slight. It was more pronounced with the greater application of phosphorus in the 15–30–15, 4–16–4, and 0–16–0 fertilizers, and became significant with longer periods of time.

TABLE 9.—*Percentage phosphorus content of soil samples collected at the sides and below the fertilizers.*

Fertilizer analysis	Days in soil							
	At sides				Below			
	2	6	10	21	2	6	10	21
4–16–4 .	0.071	0.084	0.104	0.103	0.121	0.362	0.360	0.514
15–30–15 ..	0.078	0.099	0.106	0.132	0.191	0.263	0.316	0.368
0–16–0 ...	0.047	0.057	0.041	0.041	0.072	0.160	0.208	——
2–8–8.	0.040	0.042	0.051	0.052	0.109	0.215	0.265	0.309
8–2–8. ...	0.028	0.033	0.027	0.032	0.050	0.061	0.060	0.070
8–8–2 ...	0.041	0.049	0.051	0.042	0.086	0.176	0.190	0.265

Samples of soil collected from below the fertilizers showed a more pronounced and consistent movement of phosphorus. With all the fertilizers used there was a significant increase in the movement of phosphorus after the first sampling at the end of the 2-day period. The analyses of the soil samples at the end of the 6-day period showed a further movement, and the greatest movement and accumulation of phosphorus in the soil below the fertilizer occurred at the end of the experiment.

Of special interest was the movement of phosphorus into the 2- to 3-inch layer of soil below the 16% superphosphate and the 4–16–4. After the first 2-day period the analyses of the soils for phosphorus showed an average of 0.121% under the 4–16–4 and only 0.072% under the 0–16–0. Samples of soil taken at the end of the 4-day period showed an average content of 0.362% phosphorus with the 4–16–4 and only 0.160% with the 0–16–0. The movement of phosphorus into the 2- to 3-inch layer of soil below the 4–16–4 was much more rapid than with the same amount of phosphorus in the 0–16–0. The analyses at the end of the 10-day period showed 0.360% phosphorus in the layer below the 4–16–4 and 0.208% below the 0–16–0.

The presence of potassium and nitrogen apparently facilitated the movement of phosphorus in the soil. Midgley (10) also found this to be true. In an experiment using a ¾-inch layer of Carrington silt loam held on a Büchner funnel, he noted that none of the phosphorus in superphosphate was removed by leaching with 750 cc of water. In the presence of sulfate of ammonia, about one-half the amount of phosphorus applied was found in the leachate.

The results of the analyses of the 2- to 3-inch layer of soil below the 2–8–8 and 8–8–2 fertilizers showed that an increase in nitrogen and a decrease in potash in these fertilizers caused a decrease in the movement of phosphorus in the soil. At the end of the 2-day period the soil in the 2- to 3-inch layer below the 2–8–8 fertilizer contained an average of 0.109% phosphorus, while the layer below the 8–8–2 fertilizer contained only 0.086% phosphorus After the 6-day period the phosphorus content of the soil was 0.215 and 0.176%, respectively.

The results of the analyses showing the nitrogen content of the soil samples taken at the sides and below the fertilizers are shown in Table 10. There was a pronounced movement of nitrogen in the soil in all cases. The lateral movement of nitrogen in the soil from the 4–16–4 fertilizer was not quite as great as that from the 4–0–0. Here, again, the phosphate undoubtedly interfered with the movement of nitrogen. However, the differences were not very significant.

There was about the same rate of movement of nitrogen into the samples of soil taken at the sides of 8–2–8 and 8–8–2 fertilizers. In nearly all the samples, the movement of nitrogen was greater at the sides of the 8–2–8 than of the 8–8–2. Here, again, the presence of a large amount of superphosphate apparently caused a decrease in the movement of nitrogen, probably due, as suggested before, to the formation of ammonium phosphate in the fertilizer.

In the samples taken from the 2- to 3-inch layer of soil below the fertilizer, the same condition existed, and in fact was much more evident. At the end of the 4-day period the soil below the 8–2–8 contained 0.448% nitrogen, while that below the 8–8–2 contained 0.519% nitrogen. At the end of the 6-day period the soil below the 8–2–8 contained 0.475% nitrogen while under the 8–8–2 the soil contained 0.527% nitrogen. These differences remained significant throughout the remainder of the experiment.

Soil samples collected in the 2- to 3-inch layer below the 2–8–8 showed increases in nitrogen content up to the point where practically all of the nitrogen had moved out of the fertilizer. At the end of the

4-day period the maximum was reached and the amount remained about constant up to the end of the experiment. The samples of soil collected at the sides of the 2-8-8 fertilizer showed a gradual lateral movement of nitrogen up to the close of the 10-day period and then a slight decrease as the nitrogen either moved further laterally or was carried upward with the capillary moisture.

TABLE 10.—*Average percentage nitrogen content of soils.*

Fertilizer analysis	Position of soil sample	Days in soil						
		2	4	6	8	10	14	12
4-16-4...	Side	0.130	0.126	0.118	0.165	0.153	0.158	0.148
	Below	0.268	0.288	0.391	0.410	0.375	0.366	0.364
15-30-15	Side	0.135	0.174	0.200	0.183	0.186	0.195	0.209
	Below	0.373	0.255	0.327	0.336	0.312	0.329	0.331
4-0-0	Side	0.144	0.155	0.192	0.174	0.195	0.169	0.185
	Below	0.201	0.268	0.273	0.245	0.338	0.335	0.304
2-8-8 ..	Side	0.120	0.125	0.135	0.142	0.149	0.128	0.123
	Below	0.177	0.220	0.220	0.206	0.238	0.222	0.197
8-2-8 ...	Side	0.132	0.171	0.202	0.222	0.197	0.238	0.210
	Below	0.252	0.448	0.475	0.474	0.484	0.500	0.393
8-8-2...	Side	0.148	0.162	0.185	0.213	0.216	0.227	0.188
	Below	0.352	0.519	0.527	0.514	0.542	0.796	0.505

EFFECT OF FERTILIZERS ON ELECTRICAL CONDUCTIVITY OF SOIL

The electrical resistance of soils depends upon (a) the amount of moisture, (b) the concentration of the solution, and (c) the temperature. In this experiment, the temperature and moisture were controlled and it was considered possible, therefore, to measure the soluble salts in solution at any time during the experiment. Carbon electrodes were placed in the soil in pairs, there being 2 inches between each pair of electrodes and the pairs being placed at depths of 1, 2, and 3 inches below the fertilizer. Thus an attempt was made to measure the change in conductivity of the soil solution at the different depths below a 4-16-4 fertilizer and it was considered that this change would indicate movement of salts.

With the Carrington loam soil maintained at 20% moisture there was a noticeable change in the readings of the first pair of electrodes located 1 inch below the fertilizer. This change was noted 1 hour after the fertilizer had been placed in position but became more pronounced at the reading taken about 60 hours after the experiment had been started. The second pair of electrodes showed little change in reading during the 152 hours the experiment was run. The third pair of electrodes likewise did not change from the original reading. It was concluded that soluble salt moved into the layer of soil 1 inch from the fertilizer but not as far as 2 to 3 inches. However, this was not to be expected because no water was added during the experiment.

The jars were covered to prevent evaporation and any movement that took place was due only to diffusion of soil water.

With 30% moisture in another experiment there was a much greater change in conductivity of the first and second pairs of electrodes. The third pair showed no change. The movement of salts was much more noticeable in this experiment as the diffusion of water was, no doubt, much more rapid.

Due to the difficulty in controlling all the important factors affecting conductivity, it is recognized that this method for measuring soluble salt movement may give only relative results. The only way of detecting which salts account for a change in resistance would be by a comprehensive set of experiments using different salts singly and in combination and with absolute control of moisture and temperature. The principle of the electrical conductivity measurement method for determining soluble salt movement in the soil is believed to be sound and additional work along this line is recommended

SUMMARY AND CONCLUSIONS

The results of these experiments with various fertilizers in Carrington loam permit of the following conclusions:

1. The movement of nitrogen out of the complete fertilizer tested, containing sulfate of ammonia as the source of nitrogen, was rapid.

2. The movement of phosphorus out of the complete fertilizer was rapid during the first 2 days in the soil and then the movement was noticeably retarded.

3. The movement of potassium out of the complete fertilizer was not quite as rapid as the movement of nitrogen.

4. Ammonium sulfate in the complete fertilizer apparently reduced the movement of phosphorus out of the phosphate.

5. The change in the phosphate in the complete fertilizer placed in the soil appeared to be rather sudden. Indications from the data presented are that monocalcium phosphate did not remain long in the complete fertilizer in that form. The first reaction that took place was the solution and outward movement of the readily soluble monocalcium phosphate. The remaining monocalcium phosphate then formed dicalcium phosphate, a reversion taking place within the fertilizer sample immediately after moisture from the surrounding soil had diffused into the fertilizer.

6. After a 21-day period, chemical analyses showed that about 80% of the phosphorus in the complete fertilizer was in the dicalcium phosphate form. A large part of the remaining phosphorus was present as tricalcium phosphate.

7. Sulfate of ammonia did not show any effect on the movement of potassium out of the complete fertilizer. Neither did muriate of potash appear to influence the movement of phosphorus or nitrogen.

8. The rate of movement of nitrogen in the soil was influenced by phosphorus as there was less movement and also a slower movement of nitrogen in the soil under fertilizers high in phosphorus content. The lateral movement was influenced to about the same extent.

9. The movement of phosphorus in the soil was increased by the greater amount of nitrogen present in the complete fertilizer as

sulfate of ammonia. The presence of both sulfate of ammonia and muriate of potash apparently facilitated the movement of phosphorus in the soil.

10. The effect of the movement of soluble salts in the 4-16-4 fertilizer on the conductance of an electrical current was noticeable between the first pair of electrodes located 1 inch directly below the fertilizer. A significant decrease in resistance that continued throughout the experiment indicated constant salt movement in the soil between these electrodes. The diffusion of soluble salts in the immediate vicinity of the fertilizer zone was noted within the short time of 2 hours after the fertilizer was placed in the soil. At the 2- and 3-inch depth the soluble salt diffusion due to the movement of soil moisture was not significant even at the end of 150 hours.

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RAPID CHEMICAL METHODS FOR THE ESTIMATION OF THE CAPACITY OF THE SOIL TO SUPPLY PHOSPHORIC ACID TO PLANTS[1]

G. S. Fraps and J. F. Fudge[2]

Methods for estimating the capacity of soils to supply phosphoric acid to crops are of considerable agricultural importance. The 0.2 N nitric acid method has been studied thoroughly in this laboratory (3, 4, 5),[3] and the results compared with pot experiments with favorable results on many of the soils of this state. Recently, the "Hi-lo-fosfate" method (1) and the Truog-LaMotte method have been proposed for use in field work for the rapid estimation of so-called available phosphoric acid in the soil. Truog (7) and Nemec, *et al.* (6) have proposed rapid laboratory methods. It was considered desirable to compare these methods with respect to ease of manipulation, concordance of the results on the same samples, and the relative quantities of phosphoric acid removed from soils by each. If they remove different quantities of phosphoric acid from the same soils, the interpretation of the results must vary with the method. As samples of soils tested by means of pot experiments were available, it was considered desirable also to compare the results by the various methods with the results of the pot experiments, as had been done with 0.2 N nitric acid method. Since previous work had shown the 0.2 N nitric acid method to be preferable to most of those tested, it seemed desirable to devise a rapid colorimetric method which would give similar results.

The method of Nemec is based upon the 1% citric acid used extensively in Germany and interpretated by the standards used there. The interpretation of the Hi-lo-fosfate method is based upon field observations, but data supporting the interpretation of the Truog method and of the Truog-LaMotte method have not been presented.

DESCRIPTION OF METHODS

HI-LO-FOSFATE FIELD METHOD

Some of the soil is placed in a test tube. The reagent, consisting of hydrochloric acid containing ammonium molybdate, is added. The color is developed by stirring with a tin rod and compared with the color chart.

COLORIMETRIC TRUOG LABORATORY METHOD

Two grams of soil are shaken for 30 minutes with 400 cc of 0.002 N sulfuric acid buffered with 3 grams of ammonium sulfate per liter

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Texas. Technical paper No. 206 of the Texas Agricultural Experiment Station. Also presented before American Chemical Society, New Orleans, La., March 30, 1932. Received for publication July 22, 1932.

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[3]Reference by number is to "Literature Cited," p. 229.

of solution. The phosphoric acid is estimated by the Deniges method, but modifications have been made in the strength of both the ammonium molybdate and the stannous chloride solution. The method as proposed by Truog (7) gives results as phosphorus (P), but for the sake of comparison here with other work the results are calculated to phosphoric acid (P_2O_5).

COLORIMETRIC 0.2 N NITRIC ACID METHOD

This method is based upon the regular laboratory method. After a number of preliminary experiments, the following method was adopted. Ten grams of soil are weighed into a 250-cc beaker. One hundred cc of 0.2 N nitric acid are added, using a 100-cc pipette from which the tip has been cut in order to allow rapid flow of the acid. The suspension is stirred thoroughly and allowed to set 10 minutes. After filtering (discarding the first few cc, if turbid), 5 cc is transferred to a 100-cc flask, made up to about 90 cc, and 2 cc of molybdate solution and 6 drops of stannous chloride solution are added. After development of the color, the solution is made up to the mark and mixed. The color developed is compared with standards made up in the same way and containing 0.01, 0.025, and 0.05 mgm P_2O_5. If the color developed is too strong or too weak, new solutions are made up with smaller or larger aliquots instead of the 5-cc aliquot.

The molybdate solution is made up by adding 10 grams of ammonium molybdate dissolved in 100 cc of water to 300 cc of 1–1 sulfuric acid. This is stored in a dark place. The stannous chloride is made up by dissolving 8 grams of stannous chloride in 50 cc of hydrochloric acid (or 5 grams of tin in 100 cc of hydrochloric acid) and making up to 500 cc. The solution is protected by a layer of mineral oil.

COLORIMETRIC CITRIC ACID METHOD

This method is a modification of that proposed by Nemec, *et al.* (6), which in turn is a modification of the original citric acid method proposed by Dyer (2). The method in detail as used in this work follows.

Ten grams of soil in 100 cc of 1% citric acid are shaken in an end-over-end shaking machine for 1 hour on two successive days. The suspension is filtered and to 5 cc of the filtrate are added 10 cc of 40% sulfuric acid. This solution is brought to boiling over a low flame and 0.1 N potassium permanganate is slowly added until a light rose color persists. Care must be taken that on continued boiling the color does not disappear. The last traces of citric acid are sometimes slow in reacting. The permanganate must be added slowly at the beginning and at the end of the titration. The slight excess of permanganate at the end is destroyed with a drop of 0.25% hydrogen peroxide. The solution is placed in a boiling water bath for 30 minutes, then removed, diluted to about 60 cc of acid, and the excess acid neutralized with ammonium hydroxide. This is best done by means of bromphenol blue and bromthymol blue as outside indicators on a spot

plate. By tapping the stirring rod against the sides of the beaker, very little solution is removed for a trial. The end point is reached when the solution is alkaline to bromphenol blue and acid to bromthymol blue. The outside indicator is used because an inside indicator sometimes interferes with subsequent development of the blue phosphoric acid color. The solution is then transferred to a 100-cc volumetric flask, cooled, and made up to about 90 cc. From this point, the procedure is similar to that of the colorimetric Truog method.

LABORATORY METHOD AND POT EXPERIMENTS

The laboratory 0.2 N nitric acid method and the method for conducting the pot experiments have been described elsewhere (3, 4). The crops grown in the pot experiments were corn, followed by sorghum or kafir. The phosphoric acid taken up in the crops was used as a measure of the ability of the soil to supply phosphoric acid and is expressed as p p. m. of the soil.

COMPARISON OF METHODS

A condensed comparison of details of the various methods used is given in Table 1. The methods vary widely in ratio of soil to solvent, strength of solvent, and in other respects. The results of the analyses made on 1 day were always compared with results secured from the same samples on subsequent days. Two analyses made at the same time on duplicate samples would usually check very well, but when made on different days, results on the same soil were sometimes not so closely concordant. Tested in this way, none of the colorimetric methods checked up as well as the regular laboratory method. In some cases there were wide variations in the results secured on the same soil on different dates. This was particularly the case with the Hi-lo-fosfate method and the citric acid method.

TABLE 1.—*Comparison of essential points in the various methods.*

	0.2N nitric acid	Colorimetric 0.2N nitric acid	Colorimetric Truog	Colorimetric citric acid	Truog-La-Motte	Hi-lo-fosfate
Weight of soil used, grams..........	200	10	2	10	.5*	5*
Solvent used	0.2N nitric acid	0.2N nitric acid	0.002N sulfuric acid	1% citric acid	0.056 N sulfuric acid*	0.72N hydrochloric acid*
Quantity of solvent used, cc...........	2000	100	400	100	7	10*
Ratio of soil to solvent	1:10	1:10	1:200	1:10	1:14	1:2
No. of cc normal acid to 100 grams of soil.	200	200	40	143	80	150
Time of extraction....	5 hours	10 min.	30 min.	24 hrs.	1 min.	3–5 min.

*Values are only approximate since measurements are not exact.

Successive tests of the same soil by the Hi-lo-fosfate method in many cases gave highly discordant results. Consequently, it was very difficult to say whether the phosphoric acid in many soils could be classed as high, low, or medium. On account of these variations, this method cannot be considered satisfactory.

The citric acid method also tended to give discordant results but not to the extent of the Hi-lo-fosfate method. It was also a slow and tedious method and not desirable for this reason.

The Truog method, the Truog-LaMotte method, and the 0.2 N nitric acid colorimetric method were erratic to a certain extent but were satisfactory for use when checked by repetition of the work. All three were quite rapid.

The first series of results secured by the Truog method, the Truog-LaMotte method, and the citric acid method were all much too high. Results with the Truog and Truog-LaMotte methods secured in the Texas laboratory and the Wisconsin laboratory of Professor Truog differed widely. With the Truog-LaMotte method, the differences were found to be due to errors in the color chart and to impurities in the reagents. The causes of the differences with the Truog method were not exactly ascertained, but may have been due to impurities in the reagents which did not manifest themselves in the blank tests made. The difficulties were overcome and closely agreeing results secured between the two laboratories. Acknowledgment must be made here to Professor Truog for his kind cooperation.

QUANTITIES OF PHOSPHORIC ACID DISSOLVED BY THE THREE METHODS

The quantities of the phosphoric acid dissolved by the different methods were compared by averaging the results in groups of soils arranged according to the phosphoric acid taken up by the crops. This arrangement brought the same soils together into the same groups.

The average results are given in Table 2. All of the soils were included in the averages, whether the results were apparently aberrant or not. The agreement between the averages secured by the five methods is close, although those for the colorimetric Truog method are lower than those for the other methods. For many of the soils, the results by the different methods agree almost within the range of experimental error. The lower average results by the Truog method are due to a few soils whose phosphoric acid was less soluble by this method than by the other methods. For example, the amounts of phosphoric acid brought into solution from soil No. 32924 by the 0.2 N nitric acid, colorimetric 0.2 N nitric acid, colorimetric citric acid, and Truog-LaMotte methods were 105, 97, 57, and 135 p. p. m., respectively, while only 30 p. p. m. were dissolved by the colorimetric Truog method. The two crops removed only 5 p. p. m. phosphoric acid. The results by the colorimetric Truog method were more closely related to the capacity of the soil to supply phosphoric acid to the crops than the results by the other methods.

TABLE 2.—*Mean quantities of phosphoric acid soluble by different methods compared with the quantities removed from the surface soils by two crops, p.p.m.*

Phosphoric acid removed by crops	0.2N nitric acid	Colorimetric 0.2N nitric acid	Colorimetric Truog	Colorimetric citric acid	Truog-LaMotte	No. of soils
0-10 .	28.0	24.7	16.4	20.3	19.2	23
11-20 . .	34.8	36.1	24.1	36.2	34.3	31
21-30.	73.5	77.3	50.4	74.3	63.9	26
31-40.... . .	119.4	104.2	59.9	140.4	81.3	10
41+	197.8	232.3	180.9	230.7	162.3	12

In all of the groups listed in Table 2 are individual soils which contain abnormally high quantities of phosphoric acid soluble by the different methods. (See Table 3 also.) The inclusion of these soils in the calculations of the mean have a very marked influence on the values secured. Had they been omitted, a better idea of the general relation might have been obtained. For example, of the 26 soils in the 21-30 group, 3 contain very high quantities of phosphoric acid soluble in 0.2 N nitric acid compared with the phosphoric acid removed by the crops. The omission of these three soils from the calculations would have decreased the mean from 73.5 to 35.8. These soils are No. 22234, a Miller silty clay loam, with 504 p. p. m. P_2O_5 soluble by 0.2 N nitric acid and 21 p. p. m. P_2O_5 removed by crops; No. 22232, a Yahola fine sandy loam, with 412 p. p. m. P_2O_5 soluble by 0.2 N nitric acid and 25 p. p. m. P_2O_5 removed by crops; and No. 23956, a Houston black clay, with 173 p. p. m. P_2O_5 soluble by 0.2 N nitric acid and 23 p. p. m. P_2O_5 removed by crops.

These three soils are calcareous and give very high results for soluble phosphoric acid by all methods. The colorimetric Truog method does not indicate nearly such a high solubility as do the 0.2 N nitric acid methods and the colorimetric citric acid method. The Truog-LaMotte method does not indicate a higher solubility than 225 p. p. m. These facts account for the lower averages for these methods in Table 2, particularly in the two higher classes. Of the 104 surface soils listed in Table 3, 15 contain abnormally high quantities of phosphoric acid soluble by all methods. All of these 15 soils are calcareous and 12 are heavy in texture. The methods do not apply as well to the calcareous soils as to the soils low in lime.

CAUSES OF DIFFERENCES IN PHOSPHORIC ACID DISSOLVED

As previously pointed out (3), the quantity of phosphoric acid in the soil extract depends upon three groups of factors, *viz.*, (a) the quantity of phosphates exposed to the solvent and their solubility under the conditions of the extraction, (b) the solubility of soil materials which may physically protect phosphates from the action of the solvent, and (c) the power of the soil to fix phosphoric acid under the conditions of the extraction.

By experiments with phosphatic minerals in the proportion of phosphate to solvent that might occur in treatment of the soil, it was found that phosphates of lime and precipitated phosphates of iron and aluminum were completely soluble in 0.2 N nitric acid and that

TABLE 3.—*The quantity of easily soluble phosphoric acid in the soil as indicated by different methods compared with the quantity of phosphoric acid removed by two crops.*

Laboratory No.	Soil type	Acid consumed as % $CaCO_3$	Dry weight of tops of two crops		P_2O_5 removed by plants NK pot, p.p.m.	Soluble phosphoric acid, p.p.m.				
			NPK pot	NK pot		0.2N nitric acid	Colorimetric 0.2N nitric	Colorimetric Truog	Colorimetric citric acid	Truog-Lamotte
				Surface Soils						
24009	Ruston fine sandy loam	0.40	—	7.7	2	9	7	6	8	11
33141	Gainer clay	0.97	—	5.7	2	5	16	8	6	17
23954	Crockett fine sandy loam	0.70	—	2.2	3	19	18	14	20	20
9284	Fine sand	0.24	47.9	14.5	5	14	14	9	9	16
23125	Lake Charles very fine sandy loam	1.05	29.1	13.9	5	29	39	28	34	40
32924	Potter fine sandy loam	3.71	—	7.3	5	105	97	30	57	135
33128	Gainer clay	0.98	—	12.8	5	6	18	16	15	11
6884	Duval fine sandy loam	0.15	78.4	22.4	7	125	17	10	10	11
21073	Houston clay	9.78	42.6	18.8	7	14	11	25	9	12
29533	Crockett fine sandy loam	0.35	—	15.7	7	9	11	13	11	11
21785	Norfolk fine sandy loam	0.07	43.1	17.1	8	11	21	18	19	30
25783	Nueces fine sand	0.04	—	22.1	8	16	16	11	17	17
9353	Fine sandy loam	0.25	—	25.9	8	12	17	20	31	17
9331	Fine sand	0.08	50.3	18.5	8	18	13	20	31	25
9187	Duval fine sandy loam	1.32	63.5	18.7	8	33	16	16	40	22
31880	Duval fine sandy loam	0.23	—	19.0	8	7	12	6	5	9
23952	Houston clay	8.98	18.9	13.5	9	75	109	25	17	60
23968	Susquehanna fine sandy loam	0.33	—	27.8	9	20	12	14	20	17
22302	Fine sandy loam	0.30	53.5	17.1	9	13	9	11	6	16
9279	Nueces fine sand	0.17	72.0	32.2	10	16	15	14	24	22
20720	Lake Charles clay loam	0.80	89.5	26.7	10	37	34	28	41	44
29311	Amarillo fine sand	0.06	42.6	18.3	10	23	12	14	20	17
29315	Amarillo fine sandy loam	0.42	60.5	29.7	10	27	35	21	18	17
7120	Lewisville clay	0.43	73.0	28.1	11	9	24	14	14	16
7233	Fine sand	0.15	37.5	19.9	11	18	26	11	30	22
7181	Houston black clay	5.74	47.4	27.1	11	89	17	24	11	27
9183	Susquehanna fine sandy loam	0.35	67.5	23.5	11	14	20	21	37	27
6680	Fine sandy loam	0.30	85.4	32.8	12	19	32	17	44	22
7254	Fine sandy loam	0.20	38.1	29.2	12	17	24	20	33	14

9277	Clay loam	1.62	34.3	9.6	12	19	28	43	64	82
25971	Wilson clay loam	0.76	60.3	27.3	12	25	35	28	34	33
23964	Kirvin fine sandy loam	0.53	—	35.7	13	12	10	11	9	28
24011	Susquehanna fine sandy loam	0.65	—	32.6	13	16	—	15	—	17
20724	Hockley fine sandy loam	0.23	91.6	33.4	13	24	14	13	17	22
25963	Wilson fine sandy loam	0.23	64.3	28.8	13	18	18	15	27	25
31888	Webb fine sandy loam	0.26	—	27.7	13	13	12	13	13	13
33710	Houston black clay	—	—	24.7	13	20	58	40	32	100
9333	Fine sandy loam	0.27	63.2	30.1	14	22	10	18	70	30
22904	Clay loam	0.27	77.0	32.2	14	28	20	12	46	17
29523	Bowie fine sandy loam	0.26	—	28.2	14	42	45	48	59	68
33129	Bowie fine sandy loam	0.61	—	23.2	14	50	39	36	39	50
7237	Fine sandy loam	0.35	71.9	44.5	16	19	21	14	25	22
9311	Fine sandy loam	0.16	56.8	34.6	16	23	18	27	30	35
31329	Potter clay loam	6.33	—	33.6	16	306	205	35	55	80
33137	Wilson clay	2.37	—	41.0	16	22	29	24	40	22
7241	Fine sandy loam	0.27	57.6	39.9	17	31	31	25	40	35
7244	Fine sandy loam	0.13	60.0	34.1	17	18	18	18	25	24
7708	Clay loam	0.93	47.0	32.3	17	23	30	26	49	28
7225	Fine sandy loam	0.05	66.7	59.3	18	49	48	48	60	51
9378	Fine sandy loam	0.32	65.5	41.2	18	29	23	23	50	27
25969	Crockett fine sandy loam	0.30	—	53.9	18	27	16	21	31	25
22121	Orangeburg sandy loam	0.10	47.7	37.9	19	22	12	17	18	25
20579	Lake Charles clay	1.59	64.6	41.7	20	14	18	26	36	20
31170	Taber fine sandy loam		—	35.6	20	41	38	44	47	57
22234	Miller silty clay loam	4.38	63.0	42.3	21	504	549	230	311	225
25959	Irving clay	1.15	—	51.7	21	34	30	44	47	63
9347	Lake Charles clay loam	0.99	—	56.2	21	20	35	29	33	52
22236	Calumet very fine sandy loam	0.53	82.2	52.3	21	63	45	39	47	42
9161	Caddo fine sandy loam	0.25	77.5	51.8	21	29	27	27	47	27
7169	Norfolk fine sandy loam	0.13	69.7	48.2	22	45	24	13	37	16
7341	Clay loam	2.52	45.4	39.4	22	22	41	44	60	35
29525	Wilson very fine sandy loam	0.44	—	42.0	22	39	28	27	47	28
22238	Kirkland very fine sandy loam	0.40	89.1	56.6	22	77	68	35	74	40
6976	Fine sandy loam	0.55	66.7	48.2	23	36	50	36	64	52
7265	Nueces fine sand	0.09	72.0	60.0	23	48	49	38	50	44
21771	Crockett fine sandy loam	0.27	69.2	43.4	23	25	20	21	40	27
21071	Wilson clay loam	0.76	97.9	57.8	23	17	50	24	51	35
23956	Houston black clay	5.28	53.6	44.3	23	173	222	73	155	225
21075	Houston clay	10.00	42.0	51.0	23	16	17	21	8	40
22901	Greenville fine sandy loam	0.53	67.7	47.9	24	8	11	10	13	17
7159	Fine sandy loam	0.37	64.4	55.1	25	43	44	41	52	49
22232	Yahola very fine sandy loam	3.83	44.8	39.8	25	412	368	250	407	225

TABLE 3.—*Concluded.*

Laboratory No.	Soil type	Acid consumed as % $CaCO_3$	Dry weight of tops of two crops		P_2O_5 removed by plants NK pot, p.p.m.	Soluble phosphoric acid, p.p.m.				
			NPK pot	NK pot		0.2N nitric acid	Colorometric 0.2N nitric	Colorometric Trugo	Colorometric citric acid	Truog-LaMotte
			Surface Soils							
20726	Lake Charles clay loam	1.31	97.2	60.7	25	20	27	46	37	30
18216	Cahaba fine sandy loam	0.27	68.3	58.8	26	19	23	23	33	30
22226	Vernon very fine sandy loam	0.45	87.1	58.7	28	45	37	28	56	44
22988	Clay loam	1.12	65.4	63.9	29	44	37	42	56	52
9307	Clay loam	1.33	97.7	67.7	29	18	33	35	100	68
9690	Clay loam	9.95	59.1	47.7	30	48	47	64	7	110
22230	Kirkland clay loam	1.13	72.8	52.9	30	67	96	36	64	50
31886	Duval fine sandy loam	0.21	—	48.9	30	39	31	35	36	35
23958	Wilson clay loam	1.13	88.2	72.0	33	59	56	53	44	33
21077	Wilson clay	1.62	72.9	88.9	35	31	52	34	62	55
25961	Houston black clay	5.11	61.7	61.0	36	354	330	76	112	225
22917	Fine sandy loam	0.10	41.7	39.7	36	122	89	80	106	83
9671	Fine sandy loam	0.79	62.4	64.1	36	47	46	52	296	75
25785	Willacy fine sandy loam	0.92	—	73.8	37	93	68	54	74	77
31325	Amarillo silty clay loam	0.89	—	70.2	37	259	232	116	458	90
7252	Fine sandy loam	0.12	47.1	25.3	38	48	38	23	40	32
21783	Norfolk fine sand	0.14	65.3	58.4	38	109	59	56	140	77
25967	Houston clay	1.72	—	95.2	39	72	72	55	72	66
7227	Acadia clay loam	0.75	58.2	70.9	42	39	40	36	46	44
25781	Victoria fine sandy loam	1.38	75.7	73.7	42	244	204	195	226	225
25965	Trinity clay	5.13	56.2	66.4	43	195	340	104	296	225
23950	Frio clay	10.00	73.9	64.8	44	27	37	54	23	60
32926	Washburn silty clay loam	1.20	—	74.5	46	148	121	60	122	30
18220	Trinity clay	6.99	94.3	82.9	52	167	371	93		225
18218	Houston black clay	9.54	84.1	82.9	60	38	61	72	35	200
21067	Trinity clay	8.78	83.1	80.4	61	175	95	46	15	38
31327	Randall clay	1.48	—	82.9	66	238	264	143	215	225
21069	Houston black clay	2.89	97.3	97.3	69	139	292	119	231	225
29317	Randall clay	1.43	—	95.0	76	556	550	497	714	225
23970	Houston black clay	1.80	78.2	111.8	90	408	413	390	645	225

Subsoils

32925	Potter fine sandy loam	5.14	—	1.9	1	94	100	24	41	60
33139	Wilson clay	2.03	—	5.0	2	8	17	13	15	16
33706	Bell clay	2.48	—	12.8	2	8	28	28	22	35
23963	Norfolk fine sand	0.18	—	6.7	2	10	9	10	9	11
23965	Kirvin fine sandy loam	1.05	—	8.5	2	8	8	8	9	17
21772	Crockett fine sandy loam	0.78	57.3	7.6	2	10	8	9	14	9
22122	Orangeburg fine sandy loam	0.30	39.7	8.8	4	11	7	11	18	15
9314	Houston black clay	2.00	—	10.4	4	11	45	67	91	82
21074	Houston clay	10.00	38.0	9.2	4	10	2	6	7	13
33703	Wilson clay	1.25	—	10.8	5	7	12	18	19	5
32927	Washburn silty clay loam	1.65	—	23.0	5	82	98	33	39	40
25784	Nueces fine sand	0.05	—	17.7	5	14	9	6	10	15
22228	Vernon clay loam	4.20	34.4	12.5	5	77	71	17	24	55
20581	Lake Charles clay loam	1.60	36.5	11.6	5	8	9	9	12	17
23953	Houston clay	9.78	33.9	16.2	5	42	45	17	8	47
23955	Crockett fine sandy loam	1.05	—	16.2	6	8	10	12	11	13
23124	Lake Charles very fine sandy loam	1.10	33.4	14.3	6	36	32	27	20	40
20725	Hockley fine sandy loam	0.10	77.0	22.2	7	16	8	9	6	15
21072	Wilson clay loam	0.47	81.8	16.1	7	5	—	17	23	17
33711	Houston black clay	3.95	—	16.5	7	11	32	33	17	55
25972	Wilson clay loam	1.31	63.1	23.6	7	13	12	15		13
29314	Reagan silty clay loam	10.00	38.0	19.0	7	44	37	43	18	68
22231	Kirkland clay loam	1.38	59.5	15.6	7	37	51	20	30	38
20721	Lake Charles clay loam	1.33	65.2	21.4	7	8	16	13	18	11
20580	Lake Charles clay	1.10	62.7	21.9	9	11	12	12	22	11
25960	Irving clay	1.25	63.2	34.3	10	31	18	17	22	27
23206	Hidalgo fine sandy loam	5.95	47.5	20.9	10	168	154	46	106	225
22906	Fine sandy loam	0.57	65.0	22.1	10	18	3	6	7	10
23126	Lake Charles fine sandy loam	0.73	49.8	25.7	11	38	37	38	38	40
21068	Trinity clay	9.59	52.2	29.4	12	31	17	18	12	22
22239	Kirkland very fine sandy loam	1.23	23.5	14.6	12	40	32	17	37	22
20729	Lake Charles clay	1.25	75.0	26.0	13	17	18	39	18	57
22225	Derby loamy very fine sand	0.53	79.7	31.0	13	223	151	52	186	55
23246	Brennan fine sandy loam	0.60	92.0	62.7	14	37	27	20	28	33
25786	Willacy fine sandy loam	0.88	71.5	41.6	14	40	36	20	29	22
20727	Lake Charles clay loam	1.28	83.2	30.9	14	15	19	28	15	28
23957	Houston black clay	6.95	47.5	48.6	14	149	238	56	37	225
22233	Yahola very fine sandy loam	5.08	31.2	39.5	17	429	415	193	106	225
25782	Victoria fine sandy loam	1.28	67.4	40.3	18	216	170	91	101	145
21784	Norfolk fine sand	0.09	51.6	36.8	24	40	39	37	54	40
23951	Frio clay	10.00	72.7	75.8	48	24	27	35	20	47

vivianite (ferrous phosphate) and triplite (ferrous manganese phosphate) were almost completely dissolved. The aluminum phosphates (variscite and wavellite) and basic ferric phosphate were only slightly dissolved. It follows that the phosphoric acid not dissolved by 0.2 N nitric acid is in the form of basic ferric phosphate or basic aluminum phosphate, or organic compounds, or else it is protected from the action of the solvent by encrusting material.

It has been shown (3) that soils of high fixing power may withdraw some phosphoric acid from solution in water or 0.2 N nitric acid or other solvents. However, few soils have sufficiently high fixing power to fix a large proportion of the phosphoric acid dissolved.

COMPARISON WITH POT EXPERIMENTS

Pot experiments offer the advantages over field experiments of more easily controlled conditions, greater certainty of securing samples for analysis which represent the soil used, less expense, and the possibility of using a greater number and variety of soils. They have the disadvantages of the results not being directly applicable to field conditions and not being susceptible to direct interpretation in terms of the needs of field soils. The results of pot experiments can be measured either by the weight of the crops produced by the material tested compared with a complete application, or by the quantity of the plant food taken up by the crop. As the use made of the plant food by the crop varies so that the percentage in the crop varies from one soil to another, the amount of plant food taken up is a better measure of what the soil can supply than is the weight of the crop. We are concerned with the quantity of plant food that the soil can supply and not with the use made of the plant food by the crops.

Samples of soils used in a number of pot experiments were available in sufficient quantity to use in testing the methods studied. Table 3 contains the detailed results of the work, with the samples arranged in order according to the quantity of phosphoric acid (P_2O_5) withdrawn by two crops expressed in p. p. m. of the soil. There are some kinds of soils to which none of the methods apply very well, though with the majority there are close relations between the phosphoric acid withdrawn by the crops and the phosphoric acid dissolved from the soil.

The results in Table 3 can be grouped in several ways to ascertain the relation between the analytical results and the results of the pot experiments. Two such groupings are shown in Table 4. The limits taken are purely arbitrary for the purposes of this discussion and have no reference to anything except the data presented. The close agreement between results by the different methods is shown by the data as assembled in Table 4. The agreement between the two 0.2 N nitric acid methods and the colorimetric Truog method is better than between these and the citric acid and Truog-LaMotte methods. If the group of soils be considered in which phosphoric acid found by analysis was 0–20 p. p. m., the two latter methods give a higher percentage of accord with the pot experiments than do the other three. If the group based on 0–30 p. p. m. be considered, there is almost no difference between the several methods. Thus, of all the soils which contained less than 30 p. p. m. of phosphoric acid soluble

TABLE 4.—*Relation of analysis of surface soils to quantity of phosphoric acid removed by crops.*

Method	Group: Phosphoric acid found by analysis, p.p.m.	Group: Number of soils	Percentage of total soils in group from which two crops removed the quantity of phosphoric acid designated, p.p.m.: 0–10	11–20	21–30	31–40	41+
0.2 N nitric acid	0–20	34	44	35	21	0	0
Colorimetric 0.2 N nitric acid	0–20	33	49	42	9	0	0
Colorimetric Truog	0–20	33	52	42	6	0	0
Colorimetric citric acid	0–20	26	61	23	12	0	4
Truog-LaMotte	0–20	23	65	26	9	0	0
0.2 N nitric acid	0–30	53	34	45	19	0	2
Colorimetric 0.2 N nitric acid	0–30	49	35	47	18	0	0
Colorimetric Truog	0–30	58	40	41	17	2	0
Colorimetric citric acid	0–30	33	52	33	9	0	6
Truog-LaMotte	0–30	48	40	43	15	0	2
0.2 N nitric acid	31–50	22	9	23	45	14	9
Colorimetric 0.2 N nitric acid	31–50	25	12	24	48	8	8
Colorimetric Truog	31–50	23	0	30	52	9	9
Colorimetric citric acid	31–50	33	15	40	33	6	6
Truog-LaMotte	31–50	20	10	20	50	10	10
0.2 N nitric acid	51–up	27	11	8	22	26	33
Colorimetric 0.2 N nitric acid	51–up	27	7	7	19	30	37
Colorimetric Truog	51–up	21	0	0	19	33	48
Colorimetric citric acid	51–up	33	3	15	37	24	21
Truog-LaMotte	51–up	34	6	17	26	24	27

by the 0.2 N nitric acid method, 79% supplied less than 20 p. p. m. phosphoric acid to the two crops. For the colorimetric 0.2 N nitric acid, colorimetric Truog, colorimetric citric acid, and Truog-LaMotte methods, the corresponding figures were 82, 81, 85, and 83%, respectively. All of the soils containing over 50 p. p. m. of phosphoric acid by the colorimetric Truog method provided more than 21 p. p. m. phosphoric acid to the crops. From 15 to 22% of the soils containing more than 50 p. p. m. of phosphoric acid by the other methods supplied less than 20 p. p. m. to the crops. In this respect the Truog method was better than the others.

In the large number of soils studied, as already pointed out, a few unusual soils were present. In these, the high amounts of phosphoric acid dissolved were not accompanied by a correspondingly high removal of phosphoric acid by the crops in the pot experiments. The chief surface soils in this group are No. 25781, a Victoria fine sandy loam; No. 22234, a Miller clay loam; and No. 23956, a Houston black clay. The principal subsoils in which this occurred are Nos. 23206, 22225, 22233, and 25782, Hidalgo, Darby, Yahola, and Victoria fine sandy loams, and 23957, a Houston black clay. Two of these, 25782 and 23957, are subsoils under surface soils 25781 and 23956, which had the same characteristics. Five out of these eight soils responded significantly to phosphatic fertilization. In general, all the methods agree in indicating unusually high amounts of active phosphoric acid in these soils.

The relatively small number of these unusual soils is evidence that the methods used are as accurate as could be expected, since in the use of arbitrary methods such as these there will always be a few aberrant individuals. It also indicates that knowledge of the characteristics of the soil being studied enables one to interpret the results much more closely than would be indicated by the averages, groupings, and correlation coefficients here presented.

CORRELATION COEFFICIENTS

Correlation coefficients were calculated for the relation between the quantity of phosphoric acid found by analysis with the different methods and the quantity of phosphoric acid removed from the soil by the two crops. The individual calculations included all of the soils analyzed by the method concerned. In a few cases, the determination by one of the methods was not made, due to lack of a sufficient quantity of the sample. For example, the colorimetric citric acid method was not used on soil No. 9305, while all other methods were used. However, the number of such cases was quite small, and since in no case was there any outstanding aberrant result by any of the methods used, the correlation coefficients are directly comparable. These were as follows:

Colorimetric Truog: $+ .648 \pm .033$
Colorimetric citric acid: $+ .632 \pm .034$
Truog-LaMotte: $+ .574 \pm .038$
Colorimetric 0.2 N nitric acid: $+ .558 \pm .038$
0.2 N nitric acid: $+ .519 \pm .041$

The correlation coefficient was largest with the colorimetric Truog method and smallest with the 0.2 N nitric acid method.

Examination of the correlation diagram shows that the close correlation of the Truog-LaMotte method is due partly to the fact that results do not extend beyond 225 p. p. m., and it places soils containing more than this amount together in a single group, while the other methods measure the high quantity of phosphoric acid more closely and divide the soils into several groups. The colorimetric citric acid method gives a higher coefficient of correlation than the 0.2 N nitric acid methods, although the previous data and discussion show it to be somewhat inferior for most soils.

SUMMARY

Chemical methods for estimating the capacity of the soil to supply phosphoric acid, consisting of two laboratory and two field methods, were compared with a new rapid colorimetric method devised by the writers with the regular volumetric method using 0.2 N nitric acid, and with the results of pot experiments with 146 soils. The Hi-lo-fosfate field method gave erratic results on the same soil at different times and was not reliable. The colorimetric citric acid method was slow and exacting and tended to give erratic results. The other methods tested were found to be erratic to a certain extent but gave satisfactory results when properly controlled and checked and were rapid in operation. Results by the several methods for most of the soils agreed quite well, indicating that the same phosphates were being brought into solution. The colorimetric Truog method did not remove as much phosphoric acid from soils high in soluble phosphoric acid as did the two 0.2 N nitric acid methods and the colorimetric citric acid method. Usually in such cases, the Truog method was in best agreement with the pot experiments.

Results by the 0.2 N nitric acid methods (regular and colorimetric) and the colorimetric Truog method agreed quite well with the results of the pot experiments as measured by the phosphoric acid removed by crops. The relation of the colorimetric citric acid method to the results of the pot experiments was regular but not as close as with the above methods. The Truog-LaMotte method was fairly closely related to the results of the pot experiments on soils which gave low amounts of phosphoric acid to the crops, after which the relations were irregular. The Truog-LaMotte method seems to be much more reliable for field work than the Hi-lo-fosfate method.

Extreme care must be taken at all times with all of the colorimetric methods to prevent erroneous results due to impurities in the reagents or other causes of error.

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NOTES

METHODS OF EXPRESSING THE PRODUCTION OF PASTURES

In the October 1932 number of this Journal, Vinall and Semple presented a plea for greater precision in stating the amount of grazing obtained from pastures. Specifically, they favored the term "unit days" over "cow," "cattle," or "pasture days" of grazing and included a table giving the part of a "unit" represented by animals varying from 2 to 38 months of age and from 150 to 1,000 pounds in weight. Although no provision is made for animals weighing over 1,000 pounds, this is, indeed, a step in the right direction. However, we believe a move toward greater uniformity and exactness in reporting the results of grazing trials should be carried still further.

There are several criticisms of any method of expressing pasture results in "days of grazing." The more important objections are that: (1) No idea is given of the amount of supplementary feed supplied. (2) Neither the maintenance nor gains and losses in weight are considered. For example, a pasture may have carried five head with a loss of weight for a given number of days; another may have maintained five head and produced 100 pounds of gain in the same period. How is a unit of measure such as "unit days" going to express adequately the relative productivity of these two pastures? (3) In the case of milking cows, there is no distinction between heavy or light producers.

This opportunity is taken to suggest that such results be given in terms of some feeding standard instead of "unit days." There are available reasonably reliable standards for the requirements of the different classes of animals and also the nutritional values of practically any feeds with which the pasturage might be supplemented. With such standards, the production of a pasture can be computed into terms of units of feed. Of course, such calculations cannot be made if records are not kept of the weights of the animals at the beginning and end of a grazing period, of the milk produced if lactating animals are used, and feeds consumed if the pastures are supplemented. However, in any test worthy of the name, these data should be procured.

There are several different feeding standards in use at present. Kellner's "starch equivalents," Armsby's net energy values, "therms," and Henry and Morrison's "total digestible nutrients" are prominent examples of such standards. By one of these standards both the maintenance and gains, or production, can be accounted for. In the United States, the "total digestible nutrient" standard is widely used by those dealing with the rations of livestock.

In our pasture experiments at the Storrs Station, we have employed Armsby's net energy values. The Armsby and Kellner standards are based on the amounts of net energy supplied by a feed and in this respect are an advance over standards based upon digestible nutrient values. However, it is our belief that the use of any of these standards would be of great help in presenting a comprehensive picture of the effects of various practices on the production of pastures.—B. A. Brown and G. C. White, *Storrs Agricultural Experiment Station, Storrs, Conn.*

IMPROVED MODIFICATION IN THE COLUMBIA DRILL

During the winter of 1931–32 an attempt was made to modify the Columbia drill for seeding oats and barley. One of the cylinders with small holes (No. 4–12) was used and redrilled, making a total of eight holes with sloping sides 5/8 inch in width and 3/8 inch in depth. This gave a satisfactory modification for seeding oats and barley. The sloping sides to the holes are necessary to prevent kernels from lodging. Laboratory tests with the machine with different varieties of oats and barley with varying sized kernels gave such satisfactory results that it was used to seed the entire oat and barley nurseries at Logan, Utah, in 1932, and was also adopted at each of the six substations.

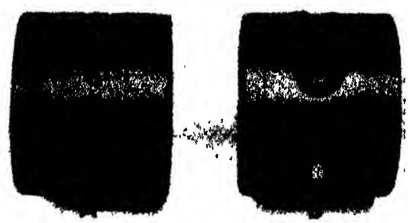

Fig. 1.—A, original cylinder. B, after modification for seeding oats and barley. Diameter 5/8 inch, depth 3/8 inch.

Soon after these modifications were made, an article appeared in this Journal (Vol. 24: 328–329) entitled "Modifications in the Columbia Drill for Seeding Oats and Barley." The writer suggested a modified cylinder in which the pairs of alternate holes were united by chiseling away the intervening metal.

In order to insure uniform seeding, the holes should be of uniform size. This can be more easily accomplished by boring than by chiseling, and since the cost of boring an entire cylinder is nominal (40 cents), this method is to be preferred. The cylinder shown in Fig. 1 has been used with success in eight Columbia drills. Where clean seed is used, there has been no difficulty in getting good uniform stands.—R. W. Woodward and D. C. Tingey, *Utah Agricultural Experiment Station, Logan, Utah.*

A READILY REMOVABLE LABEL HOLDER FOR NURSERY AND ADVANCED PLATS

A note appeared in the February (1930) issue of this Journal giving a description of a nursery plat label holder. The writer secured a sample of this label holder from Mr. Swanson, the author of the article; but it was apparent that some changes might be effected

A B C

Fig. 1.—A and B, front view of large and small size label holders, respectively; C, back view of small sized label holder, showing how it is attached to the stake.

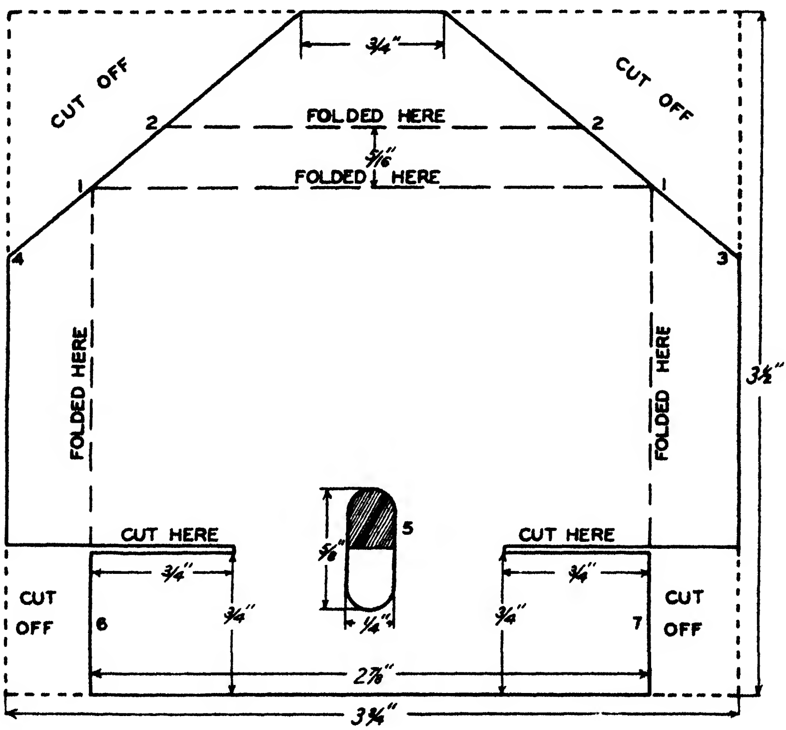

Fig. 2.—Diagram for small label holder.

Pieces of tin 3½ x 3¾ inches are used to make the small label holders. The tin is folded back along lines 1 and 2. This forms a slot which fits over the top of the stake. The sides are folded in along the dotted line 3 and 3 to form a slot on either side, which holds the tag or label. The base 6 and 7 is cut as indicated and folded back around the stake. At 5 is shown a small piece of tin pinched and bent up to hold the tag or label in place at the bottom.

which would simplify and improve it. The main disadvantage of this type of label holder is the fact that it is necessary to fasten it to the stake either by nails or screws. To do this requires considerable extra labor.

With the aid of a tinsmith, a label holder was devised which simply slips down over the top of the stake and is held firmly by two tin clasps which fold back around it (Fig. 1, C). The top of the stake fits into a tin slot which helps to hold the label holders in place Two sizes of label holders have been made, the smaller one is made from a piece of tin 3½ by 3¾ inches and the larger one from a piece 4½ by 6 inches (Fig. 2). These holders were designed for tags or labels 1⅞ by 2⅞ and 3 by 5 inches, respectively. The smaller holders will accomodate the No. I.P. tags. These can be obtained either with wire or threaded with string for tying on nursery rows at harvest. When the grain is threshed the same tag may also be used to tie the bags. A $\frac{5}{16}$-inch slot was made on the sides for the tag. A small piece of the metal was punched and bent back to hold the tag at the base. The opening of the slot is adjustable and can be readily made to hold securely labels of different thicknesses (Figs. 1 and 2).

Four thousand of these removable label holders were used at the Utah Agricultural Experiment Station during the summer of 1932, and in no case did the label holder or pasteboard tag become detached. The fact that they are simple in design and easily made makes the cost nominal—1 cent each for the small size and 3 cents each for the large size.—D. C. TINGEY and R. W. WOODWARD, *Utah Agricultural Experiment Station, Logan, Utah.*

BULK EMASCULATION OF SORGHUM FLOWERS

The need of a method for bulk emasculation of sorghum flowers was brought to our attention in 1926 and 1927 when large numbers of artificial crosses were being made for varietal improvement and for inheritance studies. Back-crossed populations were desired, but the usual method of individual floret emasculation was too slow and tedious to secure them in that way. Various possible methods of bulk emasculation were discussed, but no definite attempts were made until the summer of 1932. During the previous winter, Dr. L. J. Stadler, University of Missouri, had suggested that we try killing the pollen with hot air. No funds were available to construct a hot air chamber, but the idea of substituting hot water occurred.

The equipment (Fig. 1) used for hot water treatment of the inflorescence was as follows: A 3-pound coffee can with a hole cut in the bottom sufficiently large to pass over a sorghum head was used as the water container. A section of tire inner tube about 10 inches long was stretched over the bottom of the can, and, when in use, the other end of this tube was tied around the peduncle of the head. The can was mounted on an adjustable tripod made of plaster laths. A thermos jug, tea kettle, and termometer completed the equipment.

The success of the pollen kill without harm to other essential floral parts was determined in two ways. In some cases a few branches of the infloresćene were bagged with glassine bags immediately following treatment and the remainder of the head was left exposed to windblown pollen from surrounding plants. The effectiveness of the

treatment was determined by the seed set on the bagged and unbagged portions of the head. In other cases the treated heads were of the Schrock variety the seed of which has the character waxy endosperm, and after treatment these heads were pollinated with pollen of a variety having starchy seed. The effectiveness of the treatment was determined by the number of waxy and starchy seed set.

FIG 1.—Equipment for emasculating flowers of sorghum panicles with hot water.

The treatments were given just previous to first blooming, and when necessary the upper leaf sheath was stripped down to expose the lower portion of the inflorescence and the peduncle. Duration of treatments ranged from 5 to 15 minutes. In most trials made with temperatures above 48°C, heads were completely or partially killed or the glumes failed to open. One head was started at 48° and allowed to cool normally for 10 minutes reaching 44° in that time. In this small Schrock head, seed were set in about 50% of the spikelets. There were 362 seed and all were starchy showing the pollen kill to be complete. Another head was started at 44° and allowed to cool for 10 minutes, reaching 42°. The seed set was approximately 90%. There were 533 mature seed on this head and all were starchy. Other treatments ranging between these two, some with constant temperatures and some in which an initial temperature was secured and the water allowed to cool, were not entirely consistent, probably because of the crude procedure in which hot water was poured into the container to create or maintain the desired temperature with partial scalding resulting at times.

The possibilities of this particular method of emasculation are such, however, that it seems undesirable to delay announcing it until a definite temperature and the time duration could be given. It is apparent that there is a considerable range in temperature between the points where pollen is killed and where other floral parts are affected. Anyone interested in using the method can work out the details of successful procedure with a few trials. No doubt the method is applicable to small grains and many other field and horticultural crops, and it should be an incentive to further attempts at inter-specific and inter-generic hybridization. It is simple, rapid, and requires no expensive equipment.—J. C. STEPHENS, *Bureau of Plant Industry, U. S. Dept. of Agriculture*, and J. R. QUINBY, *Texas Agricultural Experiment Station, Chillicothe, Texas.*

AGRONOMIC AFFAIRS

THE JOURNAL REDUCED IN SIZE

On account of a sharp dropping off in collection of dues, subscriptions, and other funds owing the Society, coupled with the tying up of a considerable part of the Society's working capital by the general banking situation, it will be necessary to curtail the size of the JOURNAL, at least for the next few months. This procedure seems preferable to incurring financial obligations which the Society may or may not be able to meet later on by attempting to maintain the publication schedule that has prevailed for the past two years.

Present indications are that the JOURNAL can be kept on a monthly basis, although it may be necessary to reduce the size of later numbers still further if the Society's finances do not meet expectations. On the other hand, if collections during the year justify it, the size of the JOURNAL will be increased. It is probable, also, that some of the Society's "frozen" assets will thaw out and become available during the year.

In the meantime, may we urge the prompt payment of dues, the reinstatement of lapsed memberships, and the procuring of new members and subscriptions wherever possible as means of helping the Society and the JOURNAL through this trying period.

NEWS ITEMS

Samuel W. Phillips, a member of the Society and in charge of the erosion station of the Bureau of Chemistry and Soils at Zanesville, Ohio, was shot and killed by a burglar in his home on the night of January 23

Announcement has been made of the publication of the *Proceedings* of the Land Use Symposium held at the 1932 summer meeting of the American Association for the Advancement of Science at Syracuse, N. Y. The volume contains a discussion of the work of the National Land Use Committee, Land Use and Agriculture, Land Use and Forestry, Land Use and Erosion, Land Use and Transportation, Relation of Taxation to Land Utilization, and Planned Land Use. Further information about the *Proceedings* may be obtained from the Department of Forest Management, New York State College of Forestry, Syracuse, N. Y.

Through a committee of former Short Course graduates and members of the Wisconsin Agricultural Experiment Association, the College of Agriculture at Madison, Wisconsin, was presented with a bronze plaque and an oil painting of Professor R. A. Moore during Farm Week on February 2, 1933. Over 500 former graduates and friends of Professor Moore assembled in the Auditorium of Agricultural Hall to congratulate him and show their appreciation of his long and effective service to the people of the state. The plaque has been installed in the New Agronomy Building (with the portrait above it) and designates this building as Ransom A. Moore Hall.

Professor Moore is widely known as "Builder of the Short Course," "Father of the 4-H Club Movement," and because of his early pioneer life, the "Hunter of Kewaunee."

The new Secretary of Agriculture, the Hon. Henry A. Wallace, in addition to being an editor of note is an agronomist of no mean ability and has displayed a keen interest in the field of plant breeding, particularly with regard to corn breeding. He has been a contributor to the JOURNAL and has long supported the Society with his subscription.

Dr. John H. Parker, Professor of Plant Breeding at Kansas State College of Agriculture and Applied Science, Manhattan, Kansas, gave the fourth series of annual lectures under the Frank Azor Spragg Memorial Fund, January 24 to 27, 1933, at Michigan State College. This memorial is in honor of Professor F. A. Spragg, who was in charge of plant breeding work at the Michigan Agricultural Experiment Station from 1906 to 1924. The subjects dealt with by Dr. Parker were as follows: Disease Resistance in Crop Plants; Breeding Disease Resistant Cereals; Insect Resistance in Crop Plants; Plant Breeding Problems Related to Quality in Wheat; and Cooperation in Plant Breeding.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 APRIL, 1933 NO. 4

SOME EFFECTS OF INBREEDING IN SUGAR BEETS[1]

GEORGE STEWART[2]

During the World War and for a few years thereafter, the beet sugar industry in the western United States thrived. About 1921 it began to wane, due in part to a change in economic conditions and in part to biological disasters. In the Intermountain region two principal biological troubles have occurred intermittently, *viz.*, late root-rot and the "curly-top" disease. Late root-rot (9)[3] has caused heavy crop losses at intervals, but most serious of all have been the losses due to the curly-top disease transmitted by the sugar beet leafhopper, *Eutettix tenellus* Baker. Several severe epidemics in close succession made it apparent that a remedy must be found. Investigations had made it clear that success in controlling the insect or in directly combating the disease seemed unlikely. Plant breeding offered a possible chance for a strain of beets that might be fed upon by leafhoppers bearing curly-top virus and perhaps contract the disease but which would still produce a profitable crop of beets. Carsner (3) had demonstrated that this possibility was likely to succeed. The Spreckels Sugar Company and the University of California had also produced a resistant strain (4) known as P-19.

[1]Contribution from Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Publication authorized by Director of the Utah Agricultural Experiment Station, June 9, 1932. Received for publication August 2, 1932.

[2]Formerly Agronomist, Utah Experiment Station; now Senior Ecologist, Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah.

The writer is glad to acknowledge his indebtedness to Wesley Keller, Agent, Sugar Plant Investigations, Bureau Plant Industry, U. S. Dept. of Agriculture, Logan, Utah, for having, as student assistant and later in his present position, taken most of the measurement data reported. Except in the first seasons, Mr. Keller has also been largely responsible for most of the field work. His capable and dependable labors are highly appreciated, and it is only fair to add that without them the work could not have gone forward. At intervals valuable assistance was also received from Professors D. W. Pittman and D. C. Tingey, Utah Agricultural Experiment Station. The Franklin County Sugar Company (Idaho) and the Amalgamated Sugar Company (Utah) each generously made some hundreds of sugar tests for individual beets. One year the Amalgamated Sugar Company also made a large cash contribution to defray the cost of work done in the field. Doctors H. E. Brewbaker, F. V. Owen, and E. Carsner of the U S. Sugar Office have read this manuscript and have made many valuable suggestions. Thanks are extended to all who have helped.

[3]Reference by number is to "Literature Cited," p. 258.

The research here reported began as an effort to assist in this problem and also to improve the general agronomic qualities of sugar beets, and while this was being done to learn as much as possible about the genetics of the sugar beet plant. The present paper deals largely with preliminary genetical studies on strains derived by controlled pollination of sugar beets. Beets were selected from close-fertilized lines to begin strains, some of which became more or less homozygous for certain characters. Some of these were most promising from an agronomic point of view and crosses with the California strain (P-19) resistant to curly-top were made and with U. S. Sugar Office strain 286, but the latter proved undesirable on account of a high percentage of "bolters" (annual seed producers). Later, as a result of a cooperative project between the Utah Agricultural Experiment Station and the Office of Sugar Plant Investigations, U. S. Dept. of Agriculture, some of Carsner's more promising material was added as a resistant parent for crosses. These cross-hybridizing experiments, however, were only well begun when the writer took up other work.

PARENT MATERIAL

The strains later to be described were selected from the variety Janascz which had been grown for a number of years by the Utah Agricultural Experiment Station. This variety had been previously used in a study of seed production methods in Utah (6) and as basic material for mass selection work on sugar content. Due to its having been grown for five or six seed-generations at the Utah Station, it was probably somewhat closely bred when this experiment began. Individual isolation of progenies had never been attempted and the variety appeared in the field and milled in the sugar factory like an ordinary commercial variety. All the selections here reported came from Janascz. After a good variety test, several of the better varieties were used to add new material, but the strains thus derived were not far enough along to be included in this study.

EXPERIMENTAL PROCEDURE

In 1925, 300 well-shaped sugar beets of the Janascz variety were selected at the Utah Station. Since these beets were chosen for a small smooth crown and long tapering root that carried weight to a considerable depth without giving attention to foliage, the variety was probably approximately cross-sectioned for foliage characters. In size, the beet roots varied from 1.5 to 3 pounds. These roots were individually tested for sugar content, the sample for analysis being secured by boring a diagonal core about 1 inch in diameter. These tests showed rather wide differences in sugar content (from 12 to approximately 21%). The poorer ones were discarded until about 150 roots were left. These were stored in moist sand in a root cellar until the following spring when they were again studied as to shape. After a number that were not so well-shaped and a few that were beginning to rot were discarded, the remainder were set out in the field for seed production.

In all, 120 roots were set out for seed growing, of which exactly 100 grew and sent up seed stalks. The season of 1926 was extra-ordinarily hot and dry. It was thought that an unusually long dry period after planting accounted for most of the 20 beets that did not grow. Of the 100 growing plants, 75 were selected as showing by observation variations in habit of growth, in leaf size or shape, in foliage color or irregularities, or in depth of green coloration. Five to ten 2-pound Kraft paper grocery bags were put on branches of each plant before pollination began. According to Stewart and Tingey (10), "In some cases single small branches only were enclosed; in others a whole cluster was enclosed, so many small branches that the bags were nearly filled." Seeds were obtained from 59 of the plants, with a few plants apparently setting seed much more readily than the others. It was thought that there was indication of some plants being appreciably more self-fertile than others.

The seed matured in August, at which time the bags from each plant were examined. All bags that showed injury in any way were discarded and the others harvested by clipping off the branch at the point where the bag had been tied. After drying thoroughly, the seeds were hand-separated from the branches and counted. Rows 1 foot apart and 6 feet long were sown in the greenhouse with seeds from about 20 of the 59 plants which had set seed under bags. The seeds germinated somewhat more slowly than did ordinary beet seeds, but produced fair stands which were thinned to 10 plants in each 6-foot row. The beets grew normally until the crowded spacing became noticeable. During January, February, and March ordinary electric light globes were placed at intervals of a few feet, and were kept on from dark till about 10 p. m. Light thus used to lengthen the day-light period was thought to bring the vegetative plant into a condition to begin to send up seed stalks (5).

In March, half the beets in each row were harvested and placed for about a month in the potato cellar. The other half of each row grew until time for setting in the field, when they were harvested and set at the upper half of a row in the field, the lower half being filled with the roots harvested from the same row and placed in storage for a month. All seeded well in the field (8).

On a nearby part of the same plat of ground were seeded the remainder of the seeds grown under bags as well as some open-pollinated seeds from the same plant. Soon after emergence of the seedlings, it was observed that there were visible differences in many of the progenies from bag-grown seeds of a single parent plant. The beets grew normally, and during the fall of 1926 a few roots were selected from each strain and stored in sand in a good potato cellar.

Most of the beets grown in the greenhouse during the previous winter had developed seed stalks during the summer in the field. A few, however, developed an unusually large vegetative growth but no seed stalks. Selfed seeds were obtained from the beets that developed seed stalks by covering small branches with 2-pound grocery bags just before the flowers opened. Five to ten bags were tied to each of two or three plants in each strain of greenhouse-grown plants. Single branches only were enclosed. Cotton was placed at the base of

some of the branches where the bags were tied. As no difference could be observed in the number or quality of seeds obtained, this practice was not made general. At maturity the bagged branches were harvested as before. Some seeds were sown in the greenhouse and the remainder saved for seeding in the field the following spring.

During 1928 and 1929, a few beets resistant to curly-top were grown adjacent to a beet with desirable agronomic characters. In 1928, few known crosses were obtained as half the new beets introduced for crossing were obtained late and though seeded in the greenhouse were small in the spring and failed to flower early enough for cross-hybridizing. In 1929, this difficulty was overcome and several good crosses were obtained. In 1930, small isolated crossing plats were set out apart from the general field.

In 1928, 1929, and 1930, the process was repeated. A small number of strains grown in the greenhouse went from seed to seed each year, whereas others grown only in the field required 2 years to go from seed to seed. There were two lots of field strains, one lot producing seed one year and the other lot making vegetative growth. The succeeding year that lot which had grown seed made vegetative growth, and *vice versa*. The material had been so divided that most lines were represented each year both in the vegetative stage and in the seeding stage. This proved convenient not only in reducing the number of roots and the number of seed strains to be handled each season but served as insurance as well. One season a large percentage of roots spoiled in storage. This might have caused the loss of many of the lines, but as it was few were lost, the storage difficulty causing a year's delay in half the material and not affecting the other half in any way. Storage facilities were improved and no further trouble from root storage was encountered.

VARIABILITY STUDIES

In 1929, seed from 59 strains that had been inbred for two generations was available in some quantity, but in the third generation it had been harvested in quantity from open-pollinated branches of individual plants, thus bringing about the use of F_1 seed for some progenies. These seeds were sown in rows 40 feet long. The same year 200 strains were obtained from W. W. Tracy, who had been growing a large number of strains in the vicinity of Fort Collins, Colorado. He had used several varieties as parent material and had a magnificent collection of inbred strains, many of which were remarkable for their uniformity of widely different plant characters. He had produced an excellent collection of divergent strains.

In September, 1929, when the beets had attained their full foliage development, the first 10 healthy, well-developed beets in each progeny row were measured for leaf length and width and for petiole length and width. Immediately adjacent was the parent variety (Janascz) from which all the Logan selections had been made and 20 other varieties, including practically all the varieties Tracy had used, as well as about a dozen others. Similar measurements were made on these commercial varieties in order to compare them as to vari-

TABLE 1.—*Progenies of Tracy lines of sugar beets arranged according to leaf length classes and according to coefficient of variability classes (C.V.), grown in 1929 at Logan, Utah.**

C. V. %	Leaf length, cm													Total
	15	16	17	18	19	20	21	22	23	24	25	26	27	
3				1		2							1	4
4		1	1		1	1		1	1		1			7
5			1		1	3	2	2	2			1		12
6		2			2	6	1	3		1	1			16
7			2	2	6	1	4	2		2	1			20
8			4		3x	9x	3	2	2	2				25
9	1	1	3	1	2	7x	5	3xx	1					24
10			1	8	8x	4	2	3	x	3				29
11		1	2	3	7	7	4			2				26
12			3	1	6x	5x	1	4x	1				1	22
13			1		2	5	1		1					10
14			1			2	1							4
15								1						1
Total	1	5	19	16	38	52	24	21	8	10	3	1	2	200

*The x's stand for commercial varieties grown in a yield test immediately adjacent. These Tracy strains of beets were inbred from two to several generations. Many of them show remarkable uniformity.

TABLE 2.—*Progenies of Tracy lines of sugar beets arranged according to leaf width classes and coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Leaf width, cm												Total
	10	11	12	13	14	15	16	17	18	19	20	21	
2						1							1
3													
4					1		1						2
5			1		2								3
6		1	2	5	1	3		1					13
7		1		2	7	2	4						16
8		1	1	9	1	4	5		1				22
9				4	5	6	4	1	1			1	22
10		1		5	7	6x	3	2					24
11	1	1	4	3x	2x	8x	3						22
12			3	3	5	4	7x	1					23
13			1	7		1x							9
14	1		1	2	3	3	1		1				12
15			1	4x	2	1x		1					9
16				2	5	1	1	2					11
17				1	3x	1							5
18		1		1		1	1	1					5
19						1							1
Total	2	6	14	48	44	43	30	9	3			1	200

*The x's stand for commercial varieties grown in a yield test immediately adjacent. These Tracy strains of beets were inbred from two to several generations. Many of them show a remarkable uniformity.

ability with the inbred progenies, some of which were thought to be showing great uniformity for foliage characters. Other progenies seemed to be fully as variable, if not more so, than the parent commercial varieties.

TRACY STRAINS

In Tables 1, 2, 3, and 4 are presented the data obtained from the Tracy strains in comparison with commercial varieties, about a half dozen of which were used by Tracy as parent material. These tables show that a number of Tracy's strains are more uniform in leaf length and in leaf width than are any of the commercial varieties. There is a tendency for a few strains also to show longer leaves and others shorter leaves than the varieties. This condition is true as well for leaf width, petiole length, and petiole width. Many strains apparently are fully as variable as the parent varieties and a few even more so.

TABLE 3.—*Progenies of Tracy lines of sugar beets arranged according to petiole length classes and according to coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Petiole length, cm															Total
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
3					1											1
4																
5																
6	1		1	2				2		1						7
7						1	1	1	1	1			1			6
8				1	1	1	1	3	1	1		1				10
9			1		3	2		5	1	2		1				15
10			1		4	2	4	2	1	1	x		2			17
11					7		1	4	1	2					1	16
12					1	4	2	1	4		1	4x				17
13		1		1	2		5	3	2	x	1			3	1	19
14				2	2	6	3	2	2	x		1	2x			20
15				2	1	3	5	5	3	2	2	1				24
16				1	3				4	2	1			1	1	13
17			1	1		1		5	3	xx		x	1			12
18				1		2	x	4	1	2	1					11
19				1		1				1	1					4
20			1		1		1	1								4
21												1				1
22								1								1
23									1							1
24																
25																
26																
27																
28				1												1
Total	1	1	5	13	26	23	23	39	25	15	7	9	6	4	3	200

*The x's stand for commercial varieties grown in a yield test immediately adjacent. These Tracy strains of beets were inbred from two to several generations. Many of them showed remarkable uniformity.

A few of the ranges shown by the Tracy strains taken from Tables 1 and 4 regarding leaf length and petiole width are listed below to

TABLE 4.—*Progenies of Tracy lines of sugar beets arranged according to petiole width classes and according to coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Petiole width, mm												Total
	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	
2				1	1								2
4						2	1	1	1				5
6			1	2	2	2	1		2	1			11
8		1	1	3	3	10	1	2					21
10	1			8	5	8	1	3	1	2	1		30
12	1		1	7	11	8	3	3	2				36
14			3	4	8x	9	4x	1		1			30
16				5		9	2	3	2	6		1	29
18				3	4	6x	1	2	1	2		1	20
20				1	2	1	2x	1x		2			9
22				1		1xx	1	x			1		4
24			1			x	1						2
26													
28						1							1
Total	2	1	7	35	37	57	18	16	9	14	2	2	200

*The x's stand for commercial varieties grown immediately adjacent. These Tracy strains of beets were inbred from two to several generations. Many of them showed remarkable uniformity

TABLE 5.—*Progenies of sugar beet lines inbred for two generations and then crossed the third generation, arranged according to leaf length classes and according to coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Leaf length, cm									Total
	17	18	19	20	21	22	23	24	25	
4					2					2
5						1				1
6		1		1	3	1		1		7
7					4		2			6
8				1		2				3
9				1	3			2		6
10				1			1	1	1	4
11				1	1		3	1		6
12			3	1x		4	2		1	11
13	1			1	1	2		2		7
14					1	2	1			4
15										
16						1				1
17								1		1
18										
19										
20										
21								1		1
Total	1	1	3	7	15	13	9	9	2	60

*The x shows the position of the parent variety. Many of the progenies are distinctly less variable than the parent commercial variety.

indicate that segregation had occurred and that some strains were becoming less variable, that is, were approaching uniformity.

	Measurement (cm)	Coef. variability (%)
Leaf Length Characters		
Parents	20	10
Average progenies	20	10
Uniform progenies	16	4
	17	4
	18	3
	20	3
	25	4
	26	5
	27	3
Variable progenies	20	14
	21	14
	22	15
Petiole Width		
Parents	7.0	18
Average progenies	7.5	14
Uniform progenies	6.0	2
	6.5	2
	5.5	6
	7.0	4
	8.0	4
	8.5	4
Variable progenies	5.5	24
	7.0	28
	7.5	24
	9.5	22

Similar data may be set down at once regarding leaf width and petiole length by referring to Tables 2 and 3.

Without doubt, the Tracy strains show segregation. The decreased variability of some progenies is to be expected from inbreeding.

UTAH STRAINS

These data, as presented in Tables 1, 2, 3, and 4, will help to indicate whether the Utah progenies are also showing the effects of inbreeding. Table 5 presents the data on variability of leaf length for the Utah progenies. The parent variety Janascz had a mean leaf length of 20 cm and a coefficient of variability of 12%, for the one set of check beets measured. Of the 60 progenies, somewhat more than half had less variability, 25 of them having coefficients of variability of 9% or less, 10 of them 6% or less, and 2 of them 4%. Reference to Table 1 shows that this compares favorably with the Tracy strains, of which 11 out of 200 had a variability of 3 or 4% and 39 had coefficients of variability of 6% or less.

The leaf length of the Tracy strains had a somewhat greater range, extending from one strain 15 cm long to two strains 27 cm long, as compared to a range of 17 to 25 cm in the Utah strains. These differences are not of consequence, as a somewhat greater range in absolute values is natural, due to the greater number of strains in the Tracy collection.

An examination of Table 5 shows the strong tendency toward segregation by progenies with respect to leaf length. It is to be expected that a number of progenies would be less variable than the parent variety and that a few should show in the third generation as great a variability as the parent variety. The behavior of the Utah strains, therefore, is just what might be expected after inbreeding. Savizky (7) has reported that leaf length and shape and petiole length are not strongly influenced by environmental conditions.

Almost exactly the same thing is brought out in Table 6 with reference to leaf width. The parent variety with a mean leaf width of 15 cm and a coefficient of variability of 13% falls almost in the center of Table 6 which indicates segregation for both lesser and greater leaf width and proves that part of the progenies have already greatly decreased in variability and that others are as variable, with still others possibly more variable than the parent variety. Reference to Table 2, which presents the same data for the Tracy strains, shows (as with leaf length) in comparison with the Utah strains a somewhat more extended range and a somewhat greater degree of uniformity on the part of a few strains. This difference is explained by the larger number of strains and by the greater number of generations which they have been inbred.

TABLE 6.—*Progenies of sugar beet lines inbred for two generations, and then crossed the third generation, arranged according to leaf width classes and according to coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Leaf width, cm									Total
	11	12	13	14	15	16	17	18	19	
5							1			1
6										
7					1	1				2
8			1	1	1					3
9			1			1				2
10				3	4		1			8
11		1		2	3			1	1	8
12			1	3	2	3				9
13				3	x					3
14	1		1	1		2				5
15			1	1	2	1	1			6
16				2		3	1			6
17			1		3					4
18		1								1
19							1			1
20						1				1
Total	1	2	6	16	16	12	5	1	1	60

*The x shows the position of the parent variety. Many of the progenies were distinctly less variable than the parent commercial variety.

In Table 7, similar data are given for petiole length of the Utah strains. The parent variety had a mean petiole length of 19 cm and a coefficient of variability of 18%. There is a wide segregation, especially toward greater petiole length. The same tendency for many of the progenies to be more uniform is shown by their smaller coefficients of variability. There is a remarkable similarity between

these data and those shown for the 200 Tracy strains in Table 3, as well as for the data for leaf length (Tables 1, 5) and for leaf width (Tables 2, 6).

TABLE 7.—*Progenies of sugar beet lines inbred for two generations, and then crossed the third generation, arranged according to petiole length classes and according to coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Petiole length, cm												Total
	16	17	18	19	20	21	22	23	24	25	26	27	
6									1				1
7													
8										1			1
9				3			2		1				6
10	1			1				2			1		5
11			1				1					1	3
12			1	1		1							3
13			1		1	3	1		2				8
14				1		5	1	1	1				9
15				1		3	5					1	10
16							1						1
17	1		1			1	2	1					6
18				x	1				1				2
19													
20			1					1					2
21							1	1					2
22													
23							1						1
Total	2		5	7	2	13	15	6	6	1	1	2	60

*The x shows the position on the chart of the parent variety, grown as a check. Many of the progenies are less variable than the parent commercial variety.

TABLE 8.—*Progenies of sugar beet lines inbred for two generations, and then crossed the third generation, arranged according to petiole width classes and according to coefficient of variability classes (C. V.), grown in 1929 at Logan, Utah.**

C. V. %	Petiole width, mm									Total
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	
9		1	1			1	1	1		5
10				2			1	1		4
11									1	1
12			1			1	2			4
13				2	2	2				6
14			1	1	1	2				5
15				2	2		1		1	6
16	1		1							2
17				3		2	1			6
18			2	2		2	2			8
19					1		1			2
20			1			1	3			5
21			x				1			1
22		1			1			1		3
23		1								1
24						1				1
Total	1	3	7	12	7	12	13	3	2	60

*The x shows the position of the parent variety grown as a check. Many of the progenies were distinctly less variable than the parent commercial variety.

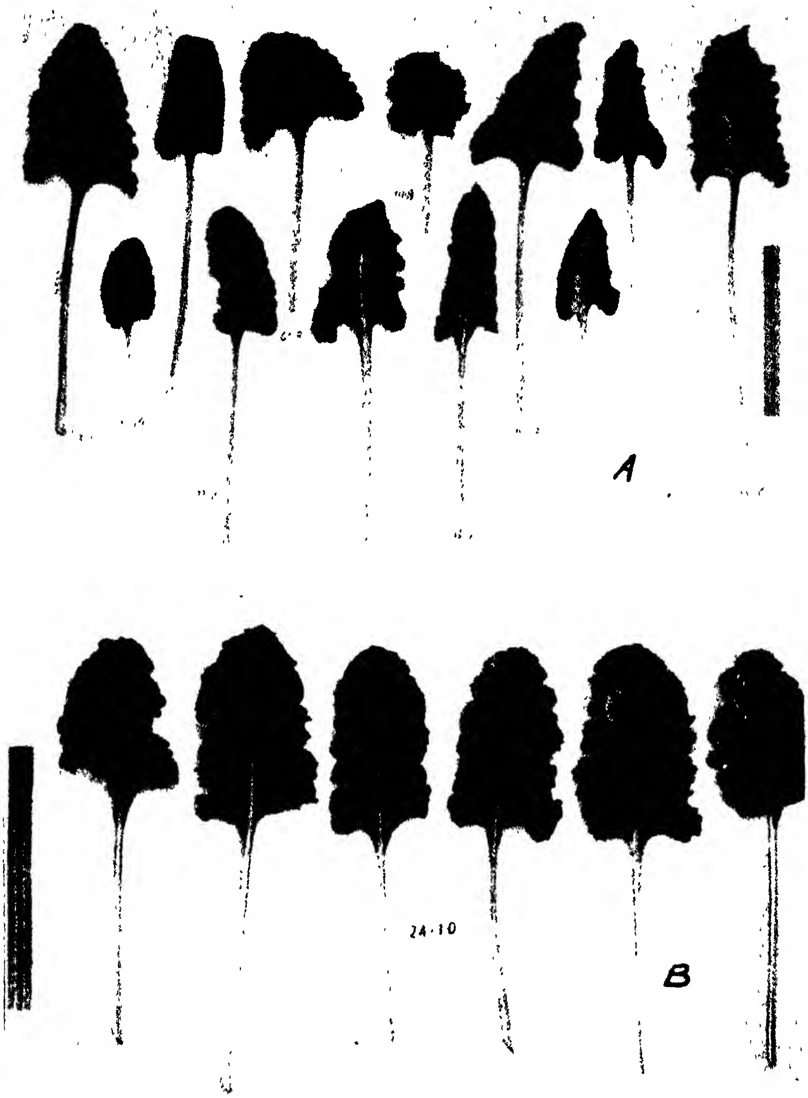

FIG. 1.—A, mature leaf and full-length petiole from each of 12 different inbred Utah strains. The relative size, shape, and smoothness of leaf and the relative length and width of petiole are brought out here. B, mature leaves and the entire length of petiole from six successive beets in Utah pedigree 24–10. The general contour of the leaves, their rounded tips, together with moderately wide petioles about 12 inches in length, all show considerable uniformity.

The data for petiole width, as presented in Table 8, show a similar segregation and a similar decrease in variability for a number of the progenies. Table 4 shows the petiole width data for the Tracy

FIG. 2.—A, mature leaves from pedigrees showing crinkled and smooth leaf surface, respectively. All the pedigrees derived from original beet No. 101 are extremely high in occurrence of crinkled leaf. B, mature leaves, one from each of six successive beets in pedigree 101-3. This Utah strain is almost entirely (perhaps fully) true-breeding for the character of crinkled leaf surface as well as for broad, short leaf and for short petiole.

strains. In comparison with the Utah strains these show a slightly greater range in absolute width of petiole and a somewhat greater uniformity in some strains.

The differences between the coefficients of variability of the parent stock and the most uniform progenies are, respectively, leaf length, $8\pm1.97\%$; leaf width, $8\pm2.10\%$; petiole length, $12\pm2.86\%$; and petiole width, $12\pm3.44\%$. For a considerable series the errors are much smaller.

OBSERVED CHARACTERS

Clear as are the measurements for segregation in leaf length and width and in petiole length and width, as a result of inbreeding, these differences are best presented by Fig. 1A, in which a representative leaf with petiole attached from each of 12 strains is shown. The leaves were all taken from the same part of the plant and represent the general type of the respective progenies. Strains 69–1, 105–5, and 160–2 have large leaves and long petioles, whereas strain 101–3 has a broad short leaf and short petiole. Strain 1927–9 has a small leaf on a long petiole. Strain 160–6 has a broad petiole, while strains 69–7, 158–4, and 1927–9 have slender ones. Strains 101–8 and 116–10 have notably short petioles. There are differences in leaf shape that were not statistically measured. In Fig. 1B are shown mature leaves, one each from the same part of successive plants in pedigree 24–10. A considerable uniformity for medium short petiole is here shown. This pedigree also shows considerable uniformity for leaf shape and size and is to be contrasted in petiole length with pedigree 160–2.

Various pedigrees of strain 101 bred almost true for a crinkled leaf surface which is compared in Fig. 2A with a smooth-leafed form. Perhaps the intervein part of the leaf grew more in proportion to the veins after these had hardened than was the case in other strains or with ordinary varieties. That pedigree 101–3 is highly uniform for this crinkled surface, as well as for a broad short leaf, is shown in Fig. 2B. The foliage is dark green, vigorous, healthy, and normal in all respects that can be observed, except for this extremely crinkled surface.

As might be expected, the strains showed equally striking differences during the seed-producing stage. Pedigree 105, shown in Fig. 3A, grew erect with long seed branches and large seeds. The plants produced seed abundantly in the open and rather freely under bags. Some other pedigrees made almost no erect growth but spread out on the ground. Such a plant is shown at the right of Fig. 3B beside an erect plant from the same strain. One pedigree, shown in Fig. 3C, in more than half the plants, sent up a central erect seed stalk in addition to a whorl that spread out on the ground. Most striking of all, however, was pedigree 101 (Fig. 4A) which grew erect but had thousands of small leaves all the way up the seed stalks, even on the seed branches and interspersed with the seeds. In this pedigree, the seed branches are short and the seeds extremely small. The total harvest of seed in the open is only about one-tenth that of pedigree 105 (Fig. 3A) and the seed ripen a few at a time, whereas in 105 and in most of the other pedigrees they mostly ripen during a short period

of time. Pedigrees 101 and 105 are almost uniform for their respective seed-producing growth habits.

SIZE OF SEED

Relative size of seed varies at different positions on the plant, usually reaching fullest development on the upper seed-bearing branches. The Utah strains differed widely in size of seed as borne on the upper seed-bearing branches. In Fig. 4B is shown the range in seed size from this part of the plant for the different pedigrees. In the extreme upper left-hand corner is the largest seed. This was taken from pedigree 105. In the lower right-hand corner is seed from pedigree 101. The other seeds, with the weight of 20 seeds in grams, are shown in the various groups. The plants of pedigrees 101 and 105, and of two or three other strains, are almost true-breeding for their respective size of seed, whereas certain other strains have one size of seed on one plant and another size on a different plant, that is, they are still segregating for this character.

SUGAR AND OTHER CHARACTERS

During 1928, ten beets in each of 37 progenies were tested individually for percentage of sugar. Eight of these progenies had been inbred for two generations. The others had been selfed one generation and open-pollinated the second generation. The mean percentage of sugar for each progeny and the coefficient of variability are shown in Table 9. The position of the parent variety, studied in the

TABLE 9.—*Progenies of sugar beet lines in which eight lines were inbred two generations and the remainder one generation and crossed the following generation, arranged according to percentage of sugar classes and according to coefficient of variability classes (C. V.), grown in 1928 at Logan, Utah.*

C. V. %	Percentage sugar in beets								Total
	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	
1.25								1	1
1.75					1	1	2		4
2.25						2	1		3
2.75			1		2	2			5
3.25				1	1		1	2	5
3.75					1	1	1		3
4.25					1	2			3
4.75			1	1		2			4
5.25	1			1		1		1	4
5.75						2			2
6.25					1	1			2
6.75									
7.25				1					1
Total	1		2	4	7	14	5	4	37

same manner, is indicated in the table. The variability of the parent variety, grown a few rods away, was 6.75%. Considerable numbers of the progenies are much less variable than the parent variety. In sugar percentage, as in leaf and petiole characters, there is evidence of increasing uniformity due to inbreeding.

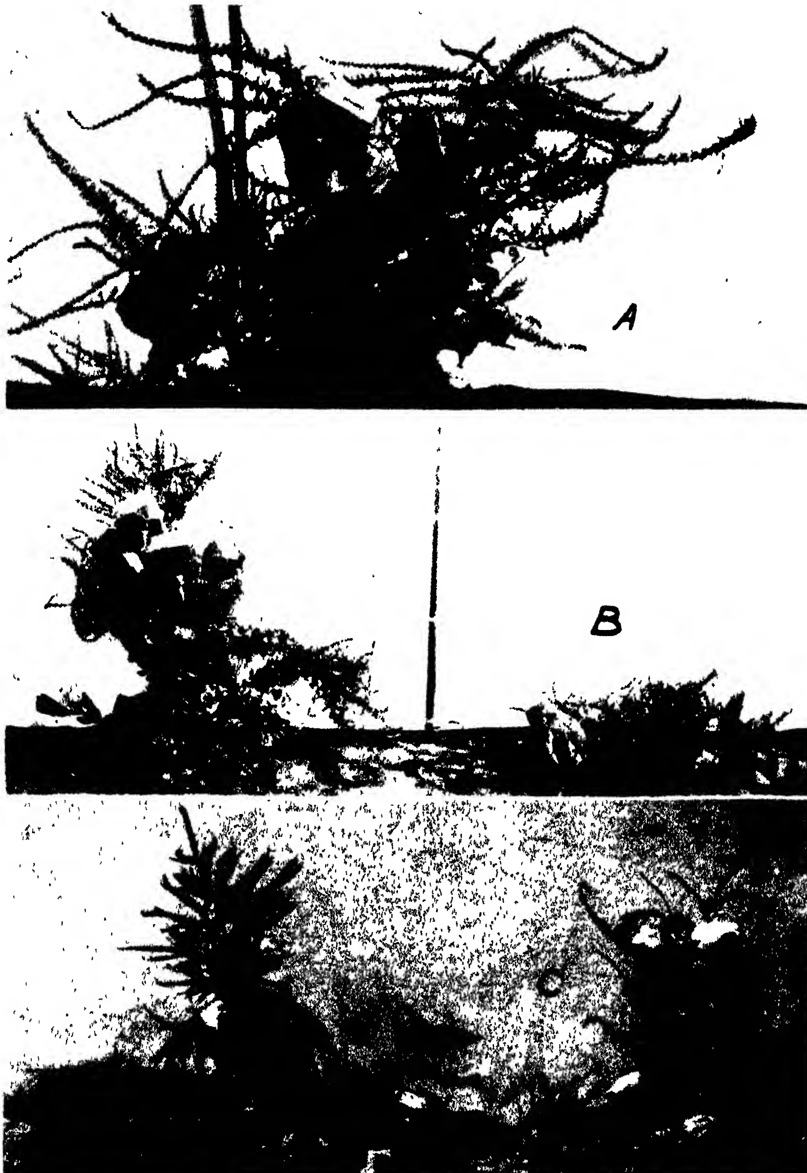

FIG. 3.—A, a seed plant from Utah pedigree 105 which stands erect, has long prolific seed branches on which the dwarfed leaflets are extremely inconspicuous. Although it cannot be seen, the seed balls on the major seed stems are large and well developed. B, erect and decumbent seed stalks on two plants of the same Utah pedigree, both grown from well-preserved roots set directly in the field from the storage cellar. C, two seed plants from well-preserved roots, showing both erect and decumbent seed stalks on the same plant. More than half the seed plants in this Utah pedigree showed this double-growth habit.

There were in the field several "selfed" strains (two generations) compared with the same strains from the same selfed plants in the first generation but harvested from unbagged branches of selfed plants in the second generation.

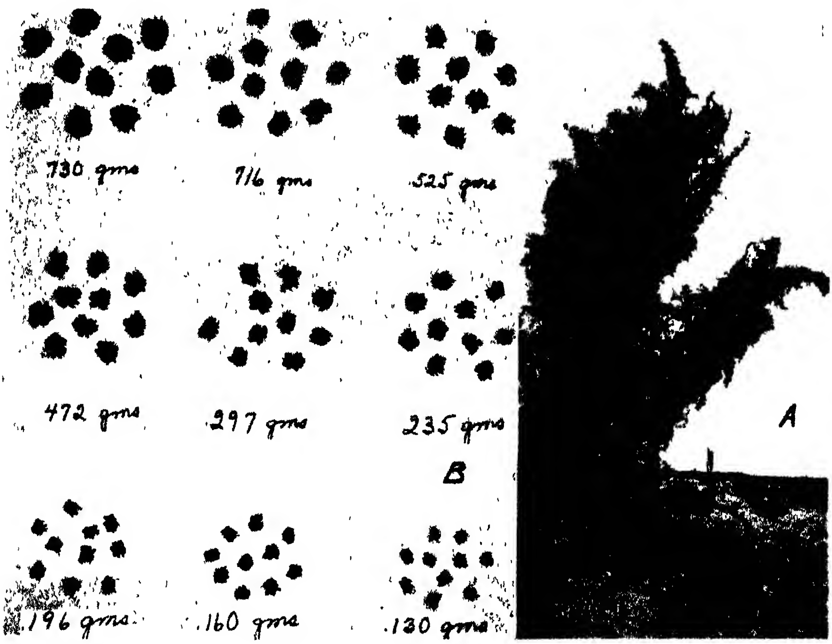

FIG. 4.—A, a typical seed plant of pedigree 101, showing erect seedstalks, covered from bottom to top with leaves, even the upper seedstalks are conspicuously leafy. Incidentally, the seeds, even on the upper branches, are extremely small. This pedigree was essentially true-breeding for this habit of seedstalk production from the time of isolation of the original beet No. 101. B, size and weight in grams of 20 seeds of various Utah pedigrees. In the upper left-hand corner are seeds from pedigree 105 and in the lower right-hand corner seeds from pedigree 101. These two pedigrees were very uniform for their respective sizes of seed. Some of the intermediate sizes showed low and others high variability. All seed is from an upper major seedstalk.

The differences in the percentage of sugar in the beets between the "selfed" and "open" beets of the same pedigree in six of the eight cases are no greater than the errors. However, in seven of the eight cases the variability of the selfed strains tends to be less than that of the same strain open-pollinated for one generation after one generation of selfing. In one case, the open-fertilized beets were less variable, but in this case the open-fertilized beets had a variability as low as the "selfed" strains. The point is that this selfed strain does not have a high variability, but that the open strain is really uniform. The eight "selfed" strains show a trend toward becoming uniform in percentage of sugar, the odds for the group by Student's method being more than 500 to 1.

Another study well worth a careful examination would be to compare the vigor of the selected and inbred lines with the parent variety. Material for this study had been collected when the writer changed positions, and the study was not made.

TABLE 10.—*Comparison of the percentage of sugar in beets of the same pedigree when selfed for two generations and when open-fertilized the second generation after having been selfed for the first generation.*

Pedigree	Selfed (two generations)		Open-fertilized (second generation)	
	% sugar	C. V. %	% sugar	C. V. %
14—6	18.6	3.46	17.6	5.97
36—2	17.6	4.82	17.8	5.63
101—3	17.7	2.07	17.6	4.25
101—9	18.2	1.61	17.4	3.63
116—4	18.1	3.47	17.2	6.03
116—9	17.5	3.35	17.6	4.99
158—6	17.3	2.93	17.7	2.42
160—4	17.3	2.99	17.0	5.00

Mention should also be made of the fact that rows of beets grown from seeds of single open-pollinated mother beets were in some cases remarkably uniform, almost as uniform as lines inbred for two or three generations. Tests were to have been made on some of these lines, but this too was not done on account of the change in position of the writer. The suggestion, however, is rather clear that the degree of heterozygosity in sugar beets is much less than has been thought, at least in certain strains.

EFFECT OF LIGHT DURING VEGETATIVE STAGE

As already indicated, beets which ordinarily take 2 years to produce seed in Utah, may, by the use of a greenhouse helped with a few hours of electric light daily, go from seed to seed each year (8). The seeds were sown in the greenhouse and were grown vegetatively during the winter. In the spring they were set out in the field to seed. The lighting in the winter of 1926–27 and again in 1927–28 was applied systematically from dark until about 10 o'clock, the exact time not being kept. The hour at which the night watchman turned off the lights varied from 9:30 to 10:30 p. m., but it was usually within about 10 minutes before or after 10 o'clock. In the winter of 1928–29 light was applied for about three weeks in March, with an hour or so in the evening from 5 to 6 o'clock during January and February.

A large number of the same pedigrees were used, thus eliminating hereditary differences of seeding habit. The data are present in Table 11 which shows the percentage of beets which seeded in the field in the summer after the greenhouse period. The light treatment is also stated. While not very complete, these data suggest that it is necessary to apply considerable light during the short winter days in order to induce seed setting when beets grown in the greenhouse during winter are transplanted to the field in the spring.

KIND OF BAG FOR SELFING

It has long been known that beet seeds are difficult to obtain when a plant is self-fertilized. As early as 1903, however, Briem (1) showed that it could be done successfully under favorable conditions.

TABLE 11.—*Percentage of beets which seeded in the field after having made their vegetative growth in the greenhouse when seeded on different dates and treated regularly or only incidentally with light.*

Pedigree No.	Seeded on					
	Little light			Regular light		
	Oct. 31, 1928	Dec. 24, 1928	Jan. 9, 1929	Nov. 1, 1926	Nov. 5, 1929	Nov. 24, 1929
14	0	0	0	90	25	0
23	14*		16*	80	71	33
24				80	25	0
28	0	0	0		93	64
36		0		27	50	12
37		0	0	90		25
51			0			
57					0	
59				60	0	0
61		0				
69	0	0		100		
101	0	0	0	80	60	0
105		0		100	71	0
116				80		
149		0				
158	100*	0	0	90	16	16
160		0	0	100	43	62
223		0				
271	0	0				
281					0	
283					25	
287					0	
503					0	0
4					25	75
5					0	
6						25
7						0
8						0
9						0
10						0
19			0			75
26		0				
36		0				
53		0				
253		0				
362		0				
374		0				
T.C+O						5
Average	10.53	0	3.33	82.45	41.67	20.94

*1 beet set seed in each case.

In 1928, a test was made to study the influence of the sort of bag on seed setting. Three types of bags were used, *viz.*, (a) ordinary Kraft grocery bags; (b) parchment bags from the corn-pollination ex-

periments of the U. S. Dept. of Agriculture in cooperation with the Indiana Agricultural Experiment Station; and (c) glassine bags. Seeds set much better under Kraft bags, as shown below:

Kind of bag	No. of bags	No. of seeds per bag
Kraft	618	2.54
Parchment	250	0.58
Glassine	75	0.30

The production of seeds under bags has not been successful in several localities where tried. It will probably be necessary to recognize that some localities are much more favorable for seed production than are others. During one extremely hot season at Logan which had warm nights during the pollination period, an extremely poor seed set was obtained under bags. It is the writer's opinion that when attention is paid to local differences favorable to seed setting, seeds will be obtained under bags in other places. Alfalfa pollination studies (2) have shown a high correlation between cool nights and seed set. Tests at Logan suggest, but do not prove, that a similar relation exists with sugar beets. At any rate there are distinct differences in localities for sugar beet seed production which deserve attention.

ABNORMALITIES

Several abnormalities have occurred in the selfed strains of beets. One of these, an extremely crinkled leaf surface, has already been mentioned. Pedigree 101–3 is almost pure for this character (Figs. 2A and 2B). Reddish-brown splotches on the leaves and albino spots have appeared on several occasions. Limitations of funds and of experimental procedure have not permitted inheritance studies of these plant characters.

One peculiarity, however, that has appeared and has been continued for three or four generations is that pedigree 160–43 is nearly, but not completely, true-breeding for a small unusual marking on the leaf. At about the 8-leaf stage, purplish-brown, somewhat circular spots a few millimeters in diameter appear in considerable numbers on the leaves. In about 2 to 3 weeks the purplish color gives way to a brown and the leaves curl. A superficial observation leads one to believe that it is curly-top. A well-trained plant pathologist and one of the leading authorities on curly-top saw this row from a distance of 3 or 4 rods and thought it the curly-top disease. However, closer examination led him to state he found no disease he recognized. It is probably another one of the weakened forms that segregate out in most plant species that have been inbred for several generations.

In the seed stage of one pedigree there is a fasciated seed stalk. It is about as thick as an ordinary seed branch but is about five to ten times as wide. It has a belt-like appearance and is somewhat more pithy inside than the ordinary seed branch. It has occurred in two generations but only occasionally, and no opportunity has been afforded to study its inheritance.

SUMMARY AND DISCUSSION

In 1925, 300 well-shaped sugar beets were selected from a commercial field of the Janascz variety. Sugar tests, later examination of root shape, and a few storage losses reduced this number to 120, of which 100 grew. A few branches of 75 of these mother beets were covered just before the flowers opened with 2-pound grocery bags and seeds were obtained under bags from 59 of the plants. Seeds from the uncovered branches of the same plants were harvested and designated as open-pollinated, whereas the seeds grown under bags were designated as selfed.

Selfed seeds from 20 of the 59 strains were sown during the fall of 1926 in the greenhouse and thinned to 10 beets in a 6-foot row. Ordinary electric light was applied from dark till 10 o'clock in the evening. In the spring five beets from each row were harvested a month early and stored in a good potato cellar. The other five were removed a month later directly to the field and planted in the same row with the ones from the cellar. All beets from seeds sown in October or November set seeds in the field in August. No difference due to storage was observed. A similar treatment was given the next fall and winter with the same result, except some strains sown in January in the greenhouse produced little seed. During the third fall and winter, due to lighting difficulties, light was applied only for an hour or so except during the last 3 weeks before the beets were transplanted to the field when it was applied from dark till 9 or 10 o'clock. When set in the field these beets seeded poorly. Each year the greenhouse grew cool at night, that is, the temperature dropped to about 50° or 55°F. In the daytime, being a horticultural house, it was kept exceptionally warm (70° to 80°F).

Each season a few strains of beets were grown in the greenhouse during the winter, thus going from seed to seed each year. Practically every strain treated this way was selfed in consecutive generations. Any selfed seeds that were not grown in the greenhouse were seeded in the field the following spring along with open-pollinated strains. All the open strains studied had greenhouse ancestry, that is, they had been selfed one, two, or more generations. Seeds from such selfed lines were harvested both from under grocery bags and from uncovered branches. Only small quantities of selfed seeds were available, but enough was always obtained to keep the lines going. The selfed seeds of some strains germinated poorly, but the seeds of other strains did almost, if not fully, as well as open seed. Meanwhile, a much larger population of seed plants was grown from roots stored over winter. These were divided into two somewhat equal groups, one for seed and one for roots each year. Nearly all strains occurred in each group.

In 1929, a large enough quantity of seeds for a field test was obtained from strains that had been selfed two or three generations but exposed to open pollination in 1928, that is, F_1 seed. Some of these strains in the field rows appeared to be highly uniform. Measurements taken on leaf length and width and on petiole length and width and compared to similar data from the commercial parent variety showed, as measured by coefficients of variability, an appre-

ciable number of strains to be more uniform in these four plant characters than was the parent variety. The Utah strains compared favorably in degree of uniformity with 200 strains selfed by W. W. Tracy by means of individual plant isolation.

Several strains from one original plant were practically uniform for a strongly crinkled leaf in the vegetative year and for extremely leafy seed stalks in the seed year and for uniformly small-sized seeds. There was a distinct segregation in the group of strains for size of seed.

Some abnormalities were found. One strain was almost pure for a leaf blotch not recognized by a well-trained plant pathologist as being any known disease. Chlorophyll was reduced and the condition seemed hereditary.

A fasciated seed stalk was found in one strain. The stalk was about as thick as a normal seed stalk and wide enough to present a belt-like appearance.

A sugar test in one year showed in some strains a trend toward uniformity for the character of sugar percentage. This was less marked than was the case with leaf characters.

During one season grocery bags were compared with glassine bags and parchment bags. More seeds were obtained under ordinary grocery bags. It was not shown that cotton around the stems at the point where the pollination bags were tied reduced the possibility of crossing.

Observation indicated that some strains lost vigor under selfing but that most others lost little or none. One selfed strain seemed more vigorous than the parent variety. However, actual measurements of vigor were not taken.

New selections from different varieties were introduced from time to time. On several occasions beets grown from the seed of a single open-pollinated beet from a commercial variety showed low variability in leaf and root characters, indicating much less heterozygosity than many workers thought beets to possess.

Observations also lead the writer to believe that variations in the production of selfed seed under bags in widely separated localities, such as Utah, Colorado, and Michigan, are likely to be found related to climate. Coolness during day or night, or both, may be a factor, though high humidity along with high temperature is thought to be unfavorable to beet seed production. This problem of location needs careful attention in beet breeding.

It seems to the writer that this incomplete work on sugar beet breeding suggests fields of study that sugar beet breeders might find profitable to explore more fully. Among these are (a) the adaptation or lack of adaptation of certain localities for growing the seed generation; (b) the kind of bags to use; (c) the relative success of bags as compared with distance isolation; (d) the production of uniform inbred strains with later crossings to unite desirable qualities, such as good production with disease-resistance, and others; (e) the study of sugar beet genetics; (f) the dropping out of the genetic composition of a variety such undesirable biotypes as deficient chlorophyll, poor or decumbent seedstalk production, and low seed-producing plants; (g) a study of relative vigor in self-fertilized lines; (h) isolation

of strains which produce seed readily under selfed conditions; and (i) the use of the greenhouse supplemented by light to speed up the breeding program.

In other words, the program would resemble in many respects that now being conducted by corn breeders. Good plant breeding methods will likely yield satisfactory results with beets as it has done with other crop plants. While the sugar beet is a difficult plant to breed, its breeding is not at all impossible.

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SOIL ORGANIC MATTER[1]

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The rôles played by organic materials in soils are not well understood. It is certain, however, that in different soils the origin, the state of decomposition, and, therefore, the agricultural value of the organic matter differ greatly, as well as that the total amount of organic matter present varies.

It is inevitable that many different meanings and functions must be assigned to the complex substances of organic origin in the soil. Some authors persist in defining all soil organic matter as "humus," although most modern workers recognize that a distinction exists between humified, well-decomposed soil organic matter and the carbonaceous substances that are intermediate between the decomposition products defined as humus, for example, by Waksman (1),[3] and the original plant materials.

Soil organic matter may quite properly be regarded as an arc of the circle of life. If we consider all living and undecomposed organic

[1]Contribution from the Department of Chemistry, Macdonald College, Quebec, Canada. Macdonald College Journal Series No. 17. Received for publication July 15, 1932.
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[3]Reference by number is to "Literature Cited," p. 265.

materials as the upper half of a circle, then soil organic materials may be considered to be the lower half. Humus may be regarded as the lowest point of the lower half of the circle and the other soil organic matter as existing at different stages of decomposition along the arc. Just as living organic substances are infinitely complex, so must soil organic substances be complex, and the breaking down of these complexes into simpler substances must in natural conditions proceed slowly. In an average soil there will be found organic matter existing in an almost infinite number of stages of decomposition.

When a plant or animal organism, or any part of such an organism, dies and its tissues are exposed to the decomposing action of soil micro-organisms, it may be regarded as soil organic matter. The soil micro-organisms themselves, because of their intimate soil contacts, may be considered to be soil organic matter. Once in contact with the soil it is differentiated through environmental influences. Biological agencies from micro-organisms to men are the chief of these. But the two factors of climate and geological origin and history of the soil minerals are the ones that affect most the biological agencies which govern soil organic matter in its accumulation or dispersion and in its decomposition to the level of humus or its lack of decomposition.

Because of their knowledge of the behaviour of culture media, microbiologists appreciate most fully the importance of the rôle played by the organic matter of the soil. This importance consists not only in the control of moisture supply to the soil organisms, but also in control of positively charged ions by absorption and directly as a source of supply for ammonium and nitrate nitrogen. It is demonstrable that it is the state of decomposition of soil organic matter that governs its capacity to serve efficiently as a "base exchange complex" (2). When their environmental conditions permit, micro-organisms are, of course, the most efficient agency in effecting the decomposition of the raw organic matter of soils.

The physical state of the soil, however, and particularly its water relationships, and the chemical equilibria in the soil solution are important factors controlling micro-organic efficiency. This is where man enters in, for by intelligent management of his soils a farmer can utilize to best advantage his soil organic matter resources.

White (3) has published figures which illustrate the rate of organic matter decay in soil under different treatments over a long period of years. Using a Pennsylvania limestone soil as experimental ground he concludes that soils of a relatively low productivity contain a higher proportion of soil organic matter to yields of air-dry matter than is true of more productive soils.

Sievers (4), in discussing soil organic matter, puts the question in these words, "What to do with this organic matter after we have it?" This question is of particular interest to soils investigators who are working with soils that are bountifully supplied with organic matter but which are relatively non-fertile.

Jenny (5) has shown that in humid climate regions of similar vegetation northern North Temperate zone soils normally contain more total nitrogen and more organic matter than southern North

Temperate zone soils. He has developed an exponential equation to prove this effect of temperature in causing soil organic matter accumulation or loss.

In New York, Bizzell (6) has shown that Volusia soils, which are very extensive and relatively infertile, contain an average of 6,400 pounds of nitrogen per acre 8 inches. He states that, "In view of the general low productive capacity of the Volusia soils, it appears that the nitrogen present is not readily available to the plant."

In Quebec Province, McKibbin and Pugsley (7) claim that high percentages of total nitrogen and of organic carbon are found in the strongly acid and relatively infertile virgin podzol soils of the Eastern Townships region. Work with long-cultivated agricultural soils of this type from the same region shows that their organic matter content is great, as evidenced by analytical results for total nitrogen and total carbon, but that nitrate nitrogen is present in but small amounts throughout the growing season. Analyses to illustrate this are given in Table 1.

TABLE 1.—*Some characteristics of long-cultivated, Appalachian upland podzol soils of Quebec.**

	Organic carbon (silica tube combustion method) %	Nitrogen (Kjeldahl method) %	Initial pH value (hydrogen electrode)	Initial lime requirement in lbs. CaO per acre (Jones' method)	Clay fraction (pipette sedimentation method) %	Nitrate nitrogen (Harper's phenoldisulfonic acid method) p.p.m. Initial	Nitrate nitrogen p.p.m. After 18 wks.
				Soil A			
Surface	3.31	0.245	5.47	4237	8.31	18.24	None
Subsoil	1.40	0.101	5.66	2226	4.56	(Apr. 27, '31)	
				Soil B			
Surface	4.11	0.304	5.42	4948	16.88	19.85	None
Subsoil	2.10	0.144	5.42	3408	13.74	(May 11, '31)	
				Soil C			
Surface	4.49	0.293	5.13	6076	14.12	25.70	10.37
Subsoil	1.74	0.096	5.24	4580	12.83	(May 25, '31)	

*Analyses are expressed on the moisture-free basis.

Soil organic matter, of course, is almost exclusively of vegetable origin. In most virgin Quebec soils, the twigs, branches, trunks, needles, or leaves of coniferous and deciduous trees account for the larger part. In peats and mucks, sedges and mosses are important sources. In long-cultivated soils much of the organic matter comes from straw. Except in mucks and peats the organic matter of agricultural soils is largely concentrated in the surface few inches. In virgin soils this fact is more apparent than in long-cultivated soils, but in the latter it is none the less true. Depending upon its source organic matter varies greatly in quality (measurable by chemical analysis) and in its readiness of decomposition by soil micro-organ-

isms. The native flora of a soil, from which its organic matter is derived, is decided to a considerable degree by the amount and the availability of the mineral nutrient elements in the soil. In this connection, plant incidence is also largely determined by soil drainage, height above mean sea level of the region, and the degree of north and south latitude. These are temperature determinants which govern the distribution of plant species and their development, as also do rainfall, sunlight, wind, and slope of terrain.

Six important groups of representative soils of the southern part of Quebec Province have been differentiated from their field characteristics, have been sampled in the virgin state, and these samples analyzed. The soils in some of these groups when cultivated are highly fertile, while in other groups are soils of relatively low productivity. Within these six groups the relatively fertile soils under normal conditions are the "heavy clays," the "sandy clays," and the "orchard" soils. The "brown earths" or "brown forest soils" are intermediate in fertility. The "Appalachian upland podzol soils" and the "lowland podzol soils" are the least fertile. The "orchard" soils may be regarded as a sub-group of the "brown earths," but they are outstandingly fertile and have some other distinguishing characteristics. Analytical data are presented in Table 2 for a number of representative virgin soils in each of the six groups, while in Table 3 are shown average and extreme ratios for some of the chemical constituents. These data are collected under the headings of the constituents determined.

Surface soils were sampled at 0 to 8 inches and subsoils at 16 to 24 inches. The analytical methods used were in general those of the A. O. A. C., and are fully described elsewhere (7). Virgin soils only were studied. In this work of differentiation of the soil groups financial assistance was given by the National Research Council of Canada. The author in these studies has worked in close cooperation with Professor P. H. H. Gray of the Bacteriology Department, Macdonald College.

It will be seen that the soils in all of the groups are extremely well supplied with organic matter. The fertile and the relatively infertile soils alike are rich in organic constituents. Two groups of soils have been mentioned as being the least fertile One, the Appalachian upland podzol group (heavily leached soils, with pronounced ash layers, occurring at about 400 feet or more above mean sea level), has surface soils containing organic matter in quantity only second to the orchard soils. The second, the lowland podzol group (heavily leached soils, with pronounced ash layers, occurring at less than about 400 feet above mean sea level), has soils containing the least organic matter among the soils in any of the groups.

In general, in the Appalachian upland podzol group of soils the acidity and the lime requirement increase as the organic carbon content of the soils increases (7). (See Fig. 1.) This is not true in the other soil groups reported. In the more fertile groups of soils the greater soil content of basic elements seems to insure a better state of decomposition of the organic matter and to insure base exchange complexes much better supplied with basic ions.

TABLE 2.—*Average and extreme percentages of some chemical constituents in soil groups of southern Quebec.*

	Average in surface soils	Average in subsoils	Lowest in surface soils	Highest in surface soils	Lowest in subsoils	Highest in subsoils
			Organic Carbon (C)			
17 heavy clays	4.45	0.55	1.85	7.83	0.17	1.58
17 sandy clays	4.02	0.60	1.36	9.51	0.25	1.29
11 lowland podzols	3.29	0.66	2.11	4.45	0.25	1.28
5 "orchard" soils	10.69	5.20	4.02	19.44	0.84	9.50
16 brown earths	4.34	1.12	2.60	6.90	0.35	2.89
25 upland podzols (Appalachian)	4.80	0.99	2.66	8.70	0.23	2.68
			Nitrogen (N)			
17 heavy clays	0.30	0.06	0.11	0.50	0.01	0.23
17 sandy clays	0.24	0.04	0.09	0.45	0.03	0.08
11 lowland podzols	0.15	0.03	0.09	0.27	0.02	0.07
5 "orchard" soils	0.71	0.35	0.34	0.97	0.09	0.58
16 brown earths	0.34	0.08	0.16	0.55	0.03	0.13
25 upland podzols (Appalachian)	0.27	0.06	0.07	0.40	0.02	0.15
			Calcium (CaO)			
17 heavy clays	2.35	2.64	1.43	4.70	1.52	4.82
17 sandy clays	2.25	2.68	1.25	3.57	1.52	3.58
11 lowland podzols	1.77	2.43	0.48	2.38	1.50	3.24
5 "orchard" soils	1.44	1.43	0.39	2.34	0.49	1.95
16 brown earths	1.40	1.57	0.64	3.13	0.63	3.73
25 upland podzols (Appalachian)	0.72	0.93	0.37	1.19	0.54	1.45
			Magnesium (MgO)			
17 heavy clays	2.55	3.16	1.54	3.86	1.32	4.56
17 sandy clays	1.72	2.49	0.69	3.06	0.86	4.11
11 lowland podzols	0.89	1.55	0.63	1.47	0.86	2.45
5 "orchard" soils	1.54	1.87	1.29	1.97	1.19	2.78
16 brown earths	1.18	1.51	0.80	2.09	0.92	2.71
25 upland podzols (Appalachian)	0.99	1.38	0.43	1.44	0.77	1.90
			Potassium (K_2O)			
17 heavy clays	2.29	2.53	1.45	3.32	1.44	3.18
17 sandy clays	2.09	2.40	1.41	2.86	1.59	3.28
11 lowland podzols	1.83	1.91	1.17	2.44	1.52	2.34
5 "orchard" soils	2.37	2.24	1.57	4.09	1.47	3.92
16 brown earths	1.69	1.82	1.38	2.11	1.45	2.38
25 upland podzols (Appalachian)	1.45	1.51	0.83	2.21	0.82	2.29
			Phosphorus (P_2O_5)			
17 heavy clays	0.22	0.16	0.12	0.34	0.05	0.32
17 sandy clays	0.17	0.17	0.08	0.37	0.02	0.29
11 lowland podzols	0.085	0.16	0.03	0.17	0.05	0.24
5 "orchard" soils	0.37	0.32	0.20	0.51	0.18	0.61
16 brown earths	0.19	0.19	0.12	0.30	0.11	0.25
25 upland podzols (Appalachian)	0.15	0.15	0.08	0.26	0.06	0.32

TABLE 2.—*Concluded.*

	Average in surface soils	Average in subsoils	Lowest in surface soils	Highest in surface soils	Lowest in subsoils	Highest in subsoils
Aluminium, Iron, and Titanium (Al_2O_3, Fe_2O_3, and TiO_2)						
17 heavy clays	22.90	26.74	18.48	27.87	23.58	30.09
17 sandy clays	19.40	23.63	13.92	27.82	17.72	28.20
11 lowland podzols	15.58	19.27	9.00	19.03	14.00	27.08
5 "orchard" soils	19.40	23.57	17.68	22.72	20.49	28.96
16 brown earths	16.71	18.17	14.00	20.94	16.20	25.12
25 upland podzols (Appalachian)	14.91	17.36	10.09	21.40	12.42	23.00

The Appalachian upland group of podzol soils is the most extensive of those mentioned here. The fertility problems that it presents for solution are largely those of unsatisfactory decomposition of organic matter, of unsaturation of the base exchange com-

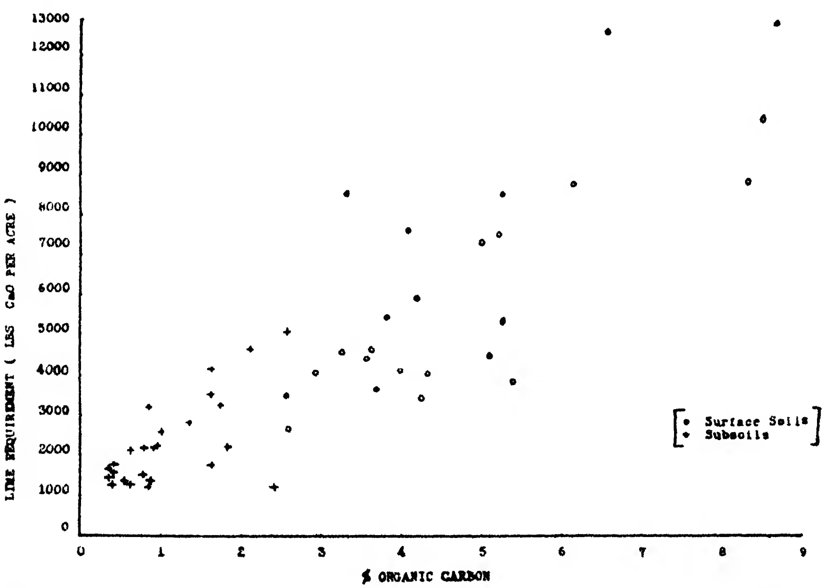

FIG. 1.—Relation between the organic carbon content of the 25 virgin Appalachian upland podsol soils and subsoils and their lime requirements.

plexes with basic ions, and of the consequent great acidity. Studies have been inaugurated on agricultural soils of this type with the end in view of their improvement. Economically feasible physical and chemical treatments are being used to build up efficient faunal and floral populations and to increase the exchange capacity as well as the basic ion content of the absorption complexes in these soils. Several departments at Macdonald College are cooperating in these studies.

The physical treatments applied are those of deep ploughing and of fallowing. Deep ploughing (10 to 12 inches) is being used to mix the

TABLE 3.—*Average and extreme ratios of some chemical constituents in the soil groups.*

	Average in surface soils	Average in subsoils	Lowest in surface soils	Highest in surface soils	Lowest in subsoils	Highest in subsoils
Silica: Iron, Aluminium, and Titanium oxides (SiO_2:Al_2O_3+Fe_2O_3+TiO_2)						
17 heavy clays......	2.58	2.22	1.66	3.39	2.71	1.78
17 sandy clays......	3.29	2.75	1.03	4.89	2.13	4.00
11 lowland podzols. .	4.79	3.92	3.40	8.96	2.47	5.42
5 "orchard" soils..	2.63	2.37	2.05	3.03	1.45	3.01
16 brown earths. ...	4.03	3.96	2.94	5.12	2.50	4.71
25 upland podzols (Appalachian)...	4.91	4.35	2.80	7.17	2.96	6.38
Carbon: Nitrogen (C/N)						
17 heavy clays.......	15.2	12.1	10.1	26.8	4.0	28.1
17 sandy clays.	14.2	14.1	10.8	25.0	5.7	27.1
11 lowland podzols. ..	22.6	21.8	12.2	41.0	7.4	64.8
5 "orchard" soils....	14.3	13.9	11.8	20.0	9.4	16.5
16 brown earths .	15.9	15.7	8.1	43.5	4.2	39.4
25 upland podzols (Appalachian)..	21.3	17.4	10.5	87.9	4.4	45.9
Magnesia: Lime (MgO/CaO)						
17 heavy clays...	1.09	1.20	0.62	1.84	0.44	1.69
17 sandy clays.....	0.77	0.93	0.37	1.07	0.44	1.76
11 lowland podzols ..	0.50	0.64	0.32	1.10	0.42	0.95
5 "orchard" soils....	1.07	1.31	0.62	3.31	0.66	3.22
16 brown earths.... .	0.84	0.96	0.43	1.67	0.48	2.78
25 upland podzols (Appalachian) ..	1.37	1.48	0.72	2.43	0.75	3.50
H-ion Concentration (pH)						
17 heavy clays... .	5.86	6.14	4.78	7.25	4.25	7.90
17 sandy clays. ...	5.55	6.32	4.66	6.97	5.35	7.24
11 lowland podzols	5.07	5.85	4.10	6.06	5.35	6.88
5 "orchard" soils....	5.75	5.75	5.04	6.45	5.14	6.59
16 brown earths. .	5.67	6.00	4.75	7.26	4.70	7.98
25 upland podzols (Appalachian)..	5.24	5.61	3.84	6.23	4.66	6.36
Lime Requirement (lbs. CaO per acre)						
17 heavy clays.....	3,581	1,422	1,200	5,650	661	3,040
17 sandy clays ..	3,569	1,217	1,982	7,121	374	3,375
11 lowland podzols	3,335	1,396	56	5,890	440	3,150
5 "orchard" soils.. .	5,904	3,482	3,040	9,150	1,200	6,750
16 brown earths..	3,868	1,659	734	6,450	none	3,840
25 upland podzols (Appalachian) .	6,220	2,307	2,700	12,980	1,200	5,100

organic matter of the surface layers with the mineral matter of the subsoils. It is hoped that dilution of the organic matter and even slight increase of the total base content in the surface soils, together with a general deepening of the layer under cultivation, if the soil is ploughed often enough to insure thorough mixing of the layers, may be beneficial to crop growth over a period of years. Fallowing suggested itself as a suitable way to aerate and to introduce oxygen for micro-organic use into these rather sodden and extremely unsaturated surface soils.

The chemical treatments include heavy applications of pulverized limestone, nitrate of soda, superphosphate, and muriate of potash, each applied annually and with no other chemical. The laboratory studies being conducted on the treated soils are based on the response of the soil micro-organisms to treatment. Changes in bacterial numbers, carbon dioxide production, nitrate nitrogen content, and acidity (pH values and lime requirement values) are being determined on samples taken at regular intervals from the soils receiving each treatment during the growing season. Chemical studies include complete analysis of the soil from each plat under treatment, and the changes effected by the different treatments in the base exchange complexes from year to year.

Laboratory work to discover the most effective and economically feasible chemical agencies for the decomposition of the organic matter of these soils has indicated sodium carbonate and burnt lime. The effect of these chemicals alone and in combination on field soils is being studied. McGeorge (8), in summing up his studies on the organic compounds associated with base exchange reactions in soils, states that, "All our investigations show that the exchange capacity of the organic fraction increases as the organic matter passes through successive stages of decomposition in the soil."

Emmert (9) has suggested the practical use of lime, sodium carbonate, and large amounts of organic matter on horticultural soils. The evidence that we possess of the base exchange capacity of the Quebec upland podzol soils is that, even when long cultivated and heavily manured with barnyard manure, they remain strongly acid and with low ability to retain basic ions. Some drastic treatment is indicated as being necessary to increase the ability of these highly organic soils to retain positively charged ions, as well as to displace hydrogen ions with desirable basic metal ions in the absorption complexes.

SUMMARY

The physical, chemical, and biological importance of soil organic matter is emphasized. Most Quebec soils, fertile and infertile, contain large amounts of nitrogen and organic carbon in their surface few inches in an acid state. Several groups of Quebec soils have been differentiated; their properties briefly discussed; and average and extreme analyses reported. Physical and chemical treatments are mentioned through the practical application of which it is hoped to modify favorably the organic matter resources of the most extensive soil group discussed, namely, the Appalachian upland podzol soils.

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NITROGEN ACCUMULATION IN SOIL AS INFLUENCED BY THE CROPPING SYSTEM[1]

T. L. LYON AND J. A. BIZZELL[2]

The nature of the cropping system practiced may be expected to affect the nitrogen content of a soil in several ways. The most obvious is by means of the quantities of nitrogen removed in crops. Nitrogen fixation through legume and non-symbiotic organisms is also an important factor. Losses in drainage water and by volatilization are possibilities. The resultant of these factors is the nitrogen level of the soil.

There is need for definite figures, in addition to those already gathered by a number of investigators, on the nitrogen fixed in a soil subjected to different cropping systems. As is to be expected there is considerable discrepancy between the results that have been obtained in different experiments. Much depends on whether the initial nitrogen content of the soil was high, and whether much nitrogen was applied during the experiment. The absence of these conditions appears to favor the fixation of atmospheric nitrogen by both symbiotic and non-symbiotic organisms or else it discourages volatilization of nitrogen and the result is a larger accumulation of total nitrogen. While experiments conducted under conditions favorable to fixation may not indicate what would occur with richer soil and larger applications of nitrogen, yet they will show the possibilities for acquisition of nitrogen under the conditions of the experiment.

The experiments here described were undertaken with a soil of medium nitrogen content and without application of nitrogen in manure or commercial fertilizer. Under these conditions nitrogen fixation may be expected to be active and loss by volatilization small or possibly absent. The conditions should be excellent, therefore, for increasing nitrogen fixation. The soil used was Dunkirk silty clay loam containing about 0.12% nitrogen at the beginning of the experiments. It was thoroughly mixed and placed in the artificial field plats, or "frames," described elsewhere. Determinations of soil nitrogen were confined to the surface 8 inches. The soil was uniform in all the frames and was sampled and analyzed at the beginning of the ex-

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periments as well as at their close. As there was no erosion by water and practically none by wind, some of the most obvious sources of error in experiments of this kind were absent.

Winter wheat was planted as the first crop on all of the frames used in the experiments. On those frames on which wheat was to be followed by a seeded crop it was sown in the wheat. There has never been much difficulty arising from winterkilling of seeded crops on the frames, although such was experienced with rims. In the case of the latter the small area which allowed the snow to become sufficiently compact to exclude air, was probably responsible for the trouble. This first crop of wheat is included in the calculations of nitrogen contained in the crops removed but is not recorded in the lists of crops contained in the various rotations. It was introduced in the rotation merely to provide a nurse crop for the seeded crops which followed on certain of the frames.

Soil samples for determinations of total nitrogen were taken before planting the first crop of winter wheat in the summer of 1918 and again in the spring of 1928. The period intervening between taking soil samples, therefore, was nearly 10 years. Since the soil samples were taken before the corn was planted in 1928, that crop is not included in the calculations of nitrogen removed by crops, which confines this to 9 years of crop production.

Alfalfa was cut several times each year and clover usually twice. Occasionally, the seeded crop was so large after the nurse crop was removed in the fall that it was cut, harvested, and analyzed. Each crop rotation covered a period of 5 years.

In the calculations of nitrogen balance in soil the first nine crops are used instead of both rounds[3] of the rotation. This was because the soil was sampled for analysis after the ninth crop had been harvested. Except in the frames on which timothy or alfalfa was grown continuously, the last 2 years of each rotation comprised corn and wheat, respectively. The yields of these two crops may be taken as a rough measure of the effect of the previous cropping.

While no nitrogen was applied to any of the frames there was a certain amount carried down by rain and snow. Determinations of the total quantity of nitrogen received by the soil in this way have been made throughout the experiment. As this figure about equaled the loss of nitrogen in drainage water, as determined by lysimeter experiments with the same type of soil, no additions or subtractions are made for either of these movements of nitrogen. To insure an adequate supply of plant nutrients other than nitrogen, lime, superphosphate, and muriate of potash were applied annually in liberal quantities to all of the frames except those in which the absence of one or more of these is stated in the descriptions. As it was impossible to maintain a continuous growth of alfalfa on this soil without at least a small application of lime, two applications of limestone at the rate of 1,000 pounds per acre were made to the alfalfa frames marked "no lime" during the 10 years. The corresponding timothy frames received no lime.

[3]In this paper the period required to grow all of the crops in a rotation is called a "round".

In Table 1 is stated for each cropping system the quantity of nitrogen contained in the crops harvested during 9 years, the loss or gain of soil nitrogen that took place between the dates on which soil samples were taken in 1918 and 1928, and from these data are calculated the accretion of nitrogen for the 9 years and the average annual accretion. These are all stated in pounds to 2,500,000 pounds of soil or approximately 1 acre to the depth of 8 inches.

The cropping systems as indicated in Table 1 list the crops grown each year of a 5-year rotation, except where alfalfa or timothy is grown continuously. Each of the crops was harvested, except in frames 20 and 44 where the clover was sown with the rye or wheat crops, and was plowed under in the late fall or early spring, when the land was prepared for the next crop. Wherever clover is mentioned red clover is meant. The annual legumes, field peas and hairy vetch, are designated merely peas and vetch. They were always planted with a cereal. The proportion of peas to oats was always larger in the timothy rotation than in the clover rotation.

The results of the experiment are so apparent from Table 1 that few comments are required. Glancing first at the column showing nitrogen contained in the crops, it is apparent that the presence of legumes, especially alfalfa, is the important factor in securing large yields of nitrogen. The more often alfalfa occurred in the rotation, the more nitrogen was contained in the crops. Timothy had the opposite effect, as may be seen by comparing the frames on which timothy occurred three times, twice, and once in the rotation.

Comparing the frames in which red clover occurred once and also those in which it occurred twice in the rotations with those in which alfalfa occurred once and twice, it is evident that the latter contained more nitrogen in the crops than did the former. The use of peas and vetch with cereals as compared with rotations containing cereals only resulted in increased yields of nitrogen for the associated legumes and non-legumes.

Losses or gains in soil nitrogen were largely a matter of whether legumes or only non-legumes occurred in the cropping system. More nitrogen was found under legumes than in the soil growing non-legumes. The more frequently alfalfa was grown in the rotation the more nitrogen was contained in the soil at the close of the experiments. Red clover grown in alternation with cereals was more potent than was alfalfa in leaving nitrogen in the soil, as may be seen by comparing frames 8 and 32 with 23, 47, and 9 and 33 with 13 and 37. Both alfalfa and red clover were more effective than the annual legumes in depositing nitrogen in the soil. The effect of field peas and hairy vetch on nitrogen accumulation in the soil was only moderate, whether they occurred once or twice in a round of the rotation. However, their growing period is short.

The total nitrogen accretion, or what may be termed apparent fixation of nitrogen, is a much more important consideration than is the nitrogen balance in the soil. This is found by adding to the quantity of nitrogen in the crops the gain of nitrogen by the soil, or subtracting the loss, if such occurred. No allowance has been made

TABLE I.—*Nitrogen balance in soil at end of the experimental period calculated to pounds per 2,500,000 pounds of soil.*

Frame Nos.	Cropping systems	Nitrogen in crops (9 years)	Nitrogen in soil, loss or gain	Apparent fixation of nitrogen during experiment	
				Total	Annual
1, 25	Timothy continuously, lime	282	—30	252	28
2, 26	Alfalfa continuously, lime	2,084	+175	2,259	251
3, 27	Timothy continuously, lime and fertilizer	278	—42	236	26
4, 28	Alfalfa continuously, lime and fertilizer	2,478	+192	2,670	297
5, 29	Timothy continuously, no lime or fertilizer	238	—72	166	18
6, 30	Alfalfa continuously, no lime or fertilizer	1,430	+45	1,475	164
7, 31	Alfalfa, alfalfa, alfalfa, corn, wheat	2,035	+62	2,097	233
8, 32	Oats, alfalfa, alfalfa, corn, wheat	1,531	+37	1,568	174
9, 33	Oats, rye, alfalfa, corn, wheat	1,117	—82	1,035	115
10, 34	Timothy, timothy, timothy, corn, wheat	277	—2	275	31
11, 35	Oats, timothy, timothy, corn, wheat	313	—37	276	31
12, 36	Oats, rye, timothy, corn, wheat	343	—172	171	19
13, 37	Clover, oats, wheat, corn, wheat	778	+185	963	107
14, 38	Timothy, oats, wheat, corn, wheat	369	—130	239	27
15, 39	Clover, oats and peas, wheat, corn, wheat	841	+257	1,098	122
16, 40	Timothy, oats and peas, wheat, corn, wheat	506	+30	536	60
17, 41	Clover, oats and peas, wheat and vetch, corn, wheat	974	+60	1,034	115
18, 42	Timothy, oats and peas, wheat and vetch, corn, wheat	631	—167	464	52
19, 43	Rye, oats and peas, wheat and vetch, corn, wheat	631	—242	389	43
20, 44	Rye and clover, oats, wheat and clover, corn, wheat	629	+57	686	63
21, 45	Rye, oats and peas, wheat, corn, wheat	508	—165	343	38
22, 46	Rye, oats, wheat, corn, wheat	374	—80	294	33
23, 47	Clover, wheat, clover, corn, wheat	1,096	+172	1,268	141
24, 48	Timothy, wheat, timothy, corn, wheat	337	—137	200	22

for the nitrogen in rain and snow, which as previously stated, approximately equals the loss in drainage water.

Alfalfa was the most potent of the legumes in nitrogen accretion, or apparent fixation. As compared with red clover where both were present 1 year in the rotation and also where both were present 2 years, there was a somewhat greater accretion of nitrogen where alfalfa was grown. Apparent fixation was perceptably greater in the soil on which peas or vetch was grown than in soil on which they were omitted from the otherwise corresponding rotations. However, in only one case in three did vetch cause more apparent fixation when grown in a rotation containing peas, than was effected by the peas alone.

Without exception every cropping system was accompanied by some accretion of nitrogen whether legumes were grown or not. It made little difference whether timothy was grown continuously or for 1, 2, or 3 years in the rotation. A rotation of cereals without a hay crop gained as much nitrogen as did the rotations containing timothy. As the average annual accretions without legumes consisted of from 20 to 30 pounds of nitrogen per 2,500,000 pounds of soil, it is evident that under these conditions a very substantial addition of nitrogen may be accomplished by a cropping system to which no nitrogen was applied other than by rain and snowfall. It must be noted, however, that as the soil had a very moderate nitrogen content at the beginning of the experiment and as no nitrogen was applied, the conditions were very favorable for nitrogen accretion.

Apparently the gain or loss of soil nitrogen resulting from a cropping system is not a very reliable guide to the productiveness of the soil even when nitrogen is the limiting factor. In other words, a soil may have suffered an appreciable decrease in nitrogen during a term of years and yet may produce as large crops as a similar soil that has gained nitrogen. The chief factor, when no nitrogen is applied, is the nature of the crop immediately preceding the one in question. On the other hand, when the preceding crop is the same, there may be little difference in yield even where there is material difference in amount of soil nitrogen. This at least is indicated by the performance of some of the frames in this experiment. In 1928 and 1929 corn and wheat respectively were grown on all frames having crop rotations. Soil analyses made in the spring of 1928 revealed differences in the nitrogen content of the soil that had developed during the course of the experiment. The gains or losses of soil nitrogen in certain frames and the combined yields of nitrogen in corn and wheat grown in 1928 and 1929 on these frames are shown in Table 2.

On frames 7 and 31, 3 years of alfalfa in two rounds of the rotation have resulted in a gain of 62 pounds of nitrogen per 2,500,000 pounds of soil. In frames 8 and 32 the 2 years of alfalfa have resulted in less gain. In frames 9 and 32, 1 year of alfalfa has been accompanied by an actual loss of 82 pounds. These figures are far from exact, of course, but doubtless they have some significance. However, whatever difference there may have been in the nitrogen content of the soil, it was not reflected in the yield of nitrogen in the crops grown in 1928 and 1929. These were practically equal.

Similar phenomena are exhibited by the rotations containing timothy. With these three rotations there were appreciable differences in the losses of soil nitrogen, but practically no differences in the yields of nitrogen in the crops grown in 1928 and 1929.

While the nitrogen content of the soil had little or no influence on the yields in 1928 and 1929, the kind of crop plants immediately preceding the corn and wheat of 1928 and 1929 exerted a very great effect on their yield. The rotations containing alfalfa yielded about twice as much nitrogen in the corn and wheat as did the rotations in which timothy was represented. It was immaterial whether the alfalfa grew for 1 year or 3 years preceding the corn and wheat, and the same was true of timothy. The determining factor was the nature of the preceding crop, i. e., whether it was alfalfa or timothy.

TABLE 2.—*Relations of gains and losses of soil nitrogen to crop yields, nitrogen in pounds per acre of crops and in 2,500,000 pounds of soil.*

Frame Nos.	Crops grown during previous years	Previously lost or gained from soil	In corn and wheat crops grown in 1928 and 1929
7, 31	Alfalfa, alfalfa, alfalfa	+ 62	139.7
8, 32	Oats, alfalfa, alfalfa	+ 37	126.6
9, 33	Oats, rye, alfalfa	— 82	131.1
10, 34	Timothy, timothy, timothy	— 2	66.1
11, 35	Oats, timothy, timothy	— 37	69.9
12, 36	Oats, rye, timothy	—172	68.8

This striking influence of the preceding crops was doubtless caused by their relative effects on the availability of the nitrogen of the soil. Since no nitrogen was applied as fertilizer, the conditions were very favorable for such an effect.

SUMMARY

The experiments were undertaken for the purpose of determining the apparent fixation of nitrogen in soil of medium nitrogen content on which various cropping systems were followed without nitrogenous fertilizer, but with lime, phosphorus, and potassium applied in liberal quantities.

The surface soil was placed in "frames." It was sampled and analyzed at the beginning and end of a period covering approximately 10 years. Nitrogen was determined in all of the crops produced and a record of the removal on each of the frames was kept for the entire period. Rain and snowfall were measured and the nitrogen in these determined monthly during the 10 years. Previous experiments with the same soil type in lysimeters furnished approximate figures on the removal of nitrogen in the drainage water.

The cropping systems consisted of the continuous growth of alfalfa and of timothy and of 5-year rotations in which alfalfa occurred from 1 to 3 years and timothy for a similar length of time, also red clover 1 and 2 years. Field peas were grown with oats and hairy vetch with wheat in some of the cropping systems. The other crops used in the rotation were fodder corn, wheat, oats, and rye.

So far as yields of nitrogen in the crops is concerned, those cropping systems that included legumes, especially alfalfa, were paramount. The more often alfalfa occurred in the rotation, the more nitrogen was contained in the crops. Timothy had the opposite effect.

Red clover was not as effective as alfalfa in producing nitrogen in the crops, either when grown once or twice in the rotation. The use of peas and vetch grown with cereals as compared with corresponding rotations in which the peas and vetch were absent resulted in increased yields of nitrogen.

At the close of the period covered by the experiment more nitrogen was contained in the soil on which legumes were grown either continuously or in alternation with non-legumes than in soil on which no legumes were grown. The more frequently alfalfa occurred in the cropping system, the more nitrogen was contained in the soil at the close of the experiment. Red clover grown in alternation with cereals was more potent than was alfalfa in leaving nitrogen in the soil. The effect of peas and vetch on nitrogen accumulation in the soil was only moderate, whether they occurred once or twice in a round of the rotation.

Accretion, or what may be termed apparent fixation of nitrogen, was found by adding to the quantity of nitrogen in the crops the gain of nitrogen by the soil, or by subtracting the loss, if such occurred. The nitrogen in rain and snowfall and that in drainage were considered to offset one another. Alfalfa was somewhat more potent than red clover in nitrogen accretion, and much more so than peas or vetch.

In the case of every cropping system there was apparent fixation of nitrogen whether legumes were grown or not. A rotation of cereals without a hay crop fixed as much nitrogen as did the rotation containing timothy. The average annual accretion of nitrogen in the cropping systems having no legumes amounted to from 20 to 30 pounds to the acre. As no nitrogen was applied in fertilizers and as the soil had a very moderate content of nitrogen the conditions were very favorable for nitrogen accretion.

The kind of crop grown immediately preceding another appeared to be a more important factor in determining the yield of nitrogen in the succeeding crop than was a previous gain or loss of soil nitrogen, at least where such differences were large. The influence of the preceding crop appears to be caused through its effect on the availability of soil nitrogen. In the case of alfalfa this was very great.

REACTION OF VARIETIES AND HYBRIDS OF WHEAT TO PHYSIOLOGIC FORMS OF BUNT[1]

E. F. Gaines and W. K. Smith[2]

In a number of the wheat-growing areas of the world severe losses are sustained annually through the ravages of stinking smut, a disease caused by *Tilletia levis* Kühn and *T. tritici* (Bjerk.) Wint. Attempts have been made to devise ways of reducing these losses by the discovery of effective and economical methods of seed treatment, by various cultural practices, and by the breeding or selection of resistant varieties desirable in other agronomic characters. Some progress has been made. The copper carbonate treatment adequately reduces infection from seed-borne spores, but in areas in which the soil is contaminated with viable inoculum at seeding time its efficiency is much reduced. The breeding of varieties resistant to this disease seemed a few years ago to be relatively simple, but the presence of physiologic forms in the two species of *Tilletia* necessitates a more comprehensive breeding program. In the Pacific Northwest *T. tritici* was the only species of the organism known to be present up to 1918. In that year one collection of bunt was found that was caused by *T. levis*. Since then Gaines (3),[3] Heald and Gaines (5), and Kienholz and Heald (6) have shown that physiologic forms of *T. tritici* and *T. levis* are now widespread in this area.

Before a breeding program to cope with this disease can be continued effectively, much data should be available on the number of physiologic forms present and on the reaction of different varieties of wheat to these forms. Studies of this nature were begun in 1927 at the Washington Agricultural Experiment Station and are being continued. Evidence gathered in 1927 on the presence of physiologic forms of bunt in the Pacific Northwest has already been described (3).

In the first part of this paper the earlier work on the differentiation of forms in the collections made in 1927 will be summarized; and the reaction of various varieties of wheat to these forms will also be described. It is desirable in a breeding program to have as much information as possible on the number of genetic factors concerned in the reaction of varieties of wheat to the prevalent physiologic forms. In the second part of the paper, the results of one of these genetic studies will be presented.

PHYSIOLOGIC FORMS AND VARIETAL REACTION

In a recent paper Aamodt (1) has given a comprehensive review of the literature on physiologic specialization in bunt and the reaction

[1]Cooperative investigations between the Washington Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Also presented before the sixth International Congress of Genetics, Ithaca, N. Y., August, 1932. Published as Scientific Paper No. 234, College of Agriculture and Experiment Station, State College of Washington. Received for publication August 9, 1932.

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[3]Reference by number is to "Literature Cited," p. 284.

of varieties to various forms. The presence of a large number of physiologic forms of both *T. levis* and *T. tritici* is now recognized, but the actual number can be determined and duplications eliminated only by testing under uniform conditions with an adequate number of differential varieties.

The five collections of bunt described by Gaines (3) in 1928 were used as inoculum at the Washington Agricultural Experiment Station on 10 varieties of winter wheat. Eight of the 10 wheats were tested in 1929 and 1930 with additional collections and are given in Table 1, *viz.*, Hohenheimer, Ridit, Hussar, Martin, Albit, Turkey (C. I. 6175), White Odessa, and Hybrid 128; the other two, Heils Dickkopf and Triplet, being eliminated as unsuited for differentiating the various bunt biotypes. It is apparent from Table 1 that the choice of differential varieties was very fortunate. Five of the eight wheats are quite susceptible to one physiologic form and strongly resistant to some other.

The methods of inoculating and growing the material and of obtaining data on the incidence of bunt have been described by Gaines and Singleton (4) and by Smith (8) and need not be repeated. Microscopic examination of the inoculum showed that two of the three collections had spores of both *T. levis* and *T. tritici*. Little difficulty, however, was experienced in separating the two species. For example, in the isolation of T2 and L5 from one collection,[4] examination of the smutted heads of Hussar showed the presence of only *T. tritici*. Inoculum for this form was therefore collected from Hussar. Examination of the spores from smutted heads of Turkey (C. I. 6175) showed that some heads were infected with *T. tritici* and others with *T. levis*. Earlier studies (7) had shown that, at least with certain varieties and certain physiologic forms of bunt, the two species are found rarely in the same head on plants growing from seed inoculated with a mixture of *T. tritici* and *T. levis*. Heads of Turkey that appeared to contain spores of *T. levis* on the basis of the examination of spores from one smut ball were used as inoculum for L5. Microscopic examination of the spores after the balls were pulverized showed that only *T. levis* was present. In a similar manner the other collection containing the two species was separated into T3 and L7. In continuing the cultures of these forms from year to year, inoculum has been collected from varieties that would eliminate or "strain out" other forms as much as possible.

Of the remaining three collections, one was *T. tritici* (T1 in Table 1), the prevalent smut in the Pacific Northwest for a number of years, and two were *T. levis*. The two collections of the latter proved to be of the same form and are represented in Table 1 by L4.

It is apparent from the results presented in Table 1 that T2 can be readily differentiated from T1 by the varieties Hussar, Martin, Albit, White Odessa, and Turkey (C. I. 6175). Also, T3 is distinct from T1 on Martin, Albit, and White Odessa. Moreover, T2 differs from T3 in its reaction to Hussar, Martin, and Turkey (C. I. 6175). Of the forms of *T. levis*, L4 gives a high percentage of bunt on Hussar,

[4]Physiologic forms designated by T and L are forms of *T. tritici* and *T. levis*, respectively.

TABLE 1.—*Reaction of 11 fall-sown wheats to nine physiologic forms of bunt in the years 1928–30, values expressed as percentage of bunted heads.*

Variety	Wash. No.	C. I. No.	T1*			T11	T3			T14	T13	T2			L5*			L4			L7	
			1928	1929	1930	1930	1929	1930	1930	1930	1930	1929	1930	1930	1929	1930	1930	1929	1930	1930	1929	1930
Turkey....	2,546	7,366	—	—	0	0	—	—	0	0	0	—	—	0	—	—	2	—	—	4	—	0
Oro......	2,550	8,220	—	0.8	0	0	0	0	0	0	0.7	0.4	0.6	0	0.6	0	3	0.1	0.6	1	0.4	0.6
Hohenheimer	2,577	11,459	33†	0.6	0	12	0.4	0	0	0	0	4	0	0	2	1	0	0	0	0	0	0
Ridit	2,324	6,703	0	0	0	0	0	0	0	0	2	2	3	4	3	2	5	.5	3	3	14	4
Hussar....	2,312	4,843	0	0	0	0	0	0	0	6	50	25	49	60	0	0	0	35	73	61	45	69
Martin....	1,092	4,463A	0	0	0	0	71	81	71	76	55	19	41	37	0	3	0	51	85	77	62	71
Albit......	2,517	8,275	0	0	0	0	77	58	70	72	37	75	89	75	0	0	1	44	79	69	72	73
White Odessa..	2,308	4,655	0	0	—	—	80	72	—	—	—	86	72	—	2	0	—	70	88	—	83	—
Turkey ...	326	6,175	0	6	2	1	2	0	1	3	29	86	83	77	72	77	65	71	86	69	71	87
Hope......	2,525	8,178	—	51	—	—	42	—	—	—	—	60	—	—	78	—	—	61	—	—	59	—
Hybrid 128	592	4,512	82	68	71	76	90	54	54	68	77	83	79	87	90	84	77	84	85	71	80	77

*T = *T. tritici*; L = *T. levis*.

†Since 1928, Hohenheimer has been smut free when inoculated with T1. Perhaps the original seed contained a susceptible strain mixture which was eliminated the first year.

Martin, Albit, and White Odessa, while L5 produces no smut or only a trace. L7 is similar to L4 in its reaction to these wheats but gives a slightly higher percentage of bunt on Ridit. It is probable, however, that L4 and L7 are two collections of the same physiologic form.

In 1930 seven further collections of bunt made by H. H. Flor were tested, and three of these, T11, T13, and T14, show differences from the forms of *T. tritici* already listed. T11 is similar to T1 but is distinguished from T1 by its reaction on Hohenheimer. In 1931, eight check rows of Hohenheimer inoculated with T11 gave an average of 31% of bunt in a test in which the susceptible check gave 79%. T13 is similar to T2 in the varieties attacked, but Albit and Turkey seem to be moderately resistant to the former and quite susceptible to the latter. Furthermore, heads of Martin smutted with T2 can be readily distinguished from heads of this variety smutted with any other known physiologic form. T14 is similar to T3, but there is 6% of bunt on Hussar while this variety is bunt free in three tests with T3. Further tests are necessary to establish T14 as a physiologic form different from T3. It may be concluded, therefore, that in Table 1 there are represented at least five physiologic forms of *T. tritici* and two forms of *T. levis*.

In the spring of 1928, 10 varieties of spring wheat were inoculated with various collections of bunt in an attempt to find varieties of spring wheat that would be suitable as differential hosts and to reveal physiological differences between the various collections. During the years 1928 to 1931 some 120 spring wheats have been tested to various individual physiologic forms and collections, and from these only 11 wheats, listed in Table 2, give any indication of being of value as differential hosts. This is rather striking in comparison with the reaction of the winter wheats to these forms. Of the 11 varieties, Martin x Marquis, Dreger's Spring, and Persicum are the most

TABLE 2.—*Reaction of 15 spring wheats to nine*

Variety	Wash. No.	C. I. No.	Percentage of bunt on varieties of wheat							
			T12	T1				T2		
			1931	1928	1929	1930	1931	1929	1930	1931
Hope	2,525	8,178	0	0	0	0.4	0.6	0	0	0.6
No. 3000	2,689	11,490	0.9	—	—	—	3	—	—	2
White Russia	2,627	11,491	—	—	6	—	—	5	—	—
Marquis	576	3,641	—	0	—	10	—	—	11	—
Ruby	2,562	6,027	3	—	—	3	0.5	—	8	8
Martin x Marquis	1,092/ 576	11,492	—	—	2	—	—	8	—	—
Axminster	2,673	8,196	0	—	—	—	5	—	—	4
Dreger's Spring	2,603	11,493	2	—	—	—	0	—	—	0
Persicum	2,607	11,494	23	—	—	—	19	—	—	8
Black Spike	2,628	11,495	0	—	—	7	4	—	40	5
Palestine	2,606	11,496	6	—	—	45	23	—	32	13
Red Fife	2,411	3,329	0.8	—	—	11	9	—	40	16
Federation	1,247	4,734	—	63	—	37	—	—	19	—
Baart	618	1,697	—	51	—	42	—	—	30	—
Jenkin	526	5,177	57	70	92	74	59	78	79	66

promising, although all are much less satisfactory than the winter wheats.

In Table 2 the same forms of bunt are included as were reported in Table 1 with the exception of T12, which is substituted for T11. Tests have not revealed any significant difference in reaction between T11 and T12. On the basis of 1- or 2-year tests, the physiologic forms, separated clearly by the reaction of winter wheats, cannot be distinguished with certainty by means of these spring wheats. It is of interest to note that Hope is the most resistant spring wheat, but when fall sown (Table 1) it is susceptible. The percentage of bunt was generally lower in 1931 than in 1930, but there are exceptions.

In Table 3 the reaction of 27 wheats to six of the physiologic forms may be compared with a mixture of forms. The most virulent form in nearly every case produced more smut than a mixture of either the *T. levis* or the *T. tritici* forms. Fortyfold, Hybrid 128, and Triplet were susceptible to all forms. The 12 at the upper end of the list were resistant to all forms thus far tested, and five of them have been built up by hybridization from wheats that are not resistant to all of these forms. In some instances added resistance seems to come from a susceptible parent, as in Albit and Jenkin x Ridit. Albit was selected from a cross between White Odessa and Hybrid 128. The difference between White Odessa and Albit apparently comes from Hybrid 128, the variety taken as the standard of susceptibility. Reference to Table 1 shows that Albit produced less smut than White Odessa in every test in 1929. In 1930, Albit showed higher infection with T2 and with both mixtures of inoculum, but the other forms all produced a higher percentage of smut on White Odessa. Jenkin is very susceptible, but the selection Jenkin x Ridit has been consistently more resistant than Ridit.

physiologic forms of bunt in the years 1928–31.

inoculated with physiologic forms in the years indicated

T14	T3			T13	L4				L7				L5			
1931	1929	1930	1931	1931	1928	1929	1930	1931	1928	1929	1930	1931	1928	1929	1930	1931
0	0	0	0.7	0.5	0	0	1	0.5	0	0	0	0	0	0	0	2
4	—	—	11	4	—	—	—	3	—	—	—	0	—	—	—	4
—	13	—	—	—	—	2	—	—	—	2	—	—	—	10	—	—
—	—	21	—	—	6	—	5	—	2	—	10	—	7	—	17	—
10	—	7	15	9	—	—	0.8	10	—	—	6	9	—	—	30	10
—	21	—	—	—	—	0	—	—	—	2	—	—	—	25	—	—
9	—	—	17	13	—	—	—	10	—	—	—	4	—	—	—	11
20	—	—	21	20	—	—	—	6	—	—	—	6	—	—	—	10
4	—	—	4	1	—	—	—	5	—	—	—	14	—	—	—	5
2	—	9	5	10	—	—	10	8	—	—	10	5	—	—	39	10
3	—	9	14	22	—	—	17	5	—	—	37	7	—	—	34	4
33	—	34	27	24	—	—	27	19	—	—	18	15	—	—	60	17
—	—	37	—	—	58	—	16	—	41	—	28	—	48	—	51	—
—	—	51	—	—	50	—	29	—	55	—	39	—	51	—	62	—
52	73	64	56	72	63	58	37	54	62	34	57	37	65	56	79	50

TABLE 3.—*Reaction of 27 winter wheats to six physiologic forms of bunt and three mixtures of forms, average of each variety given in percentage of Hybrid 128 for the tests in which it appears.*

Variety	Wash. No.	C. I. No.	Percentage of bunt on varieties of wheat inoculated with physiologic forms									Relation to Hybrid 128 as 100
			T1, 1930	T2, 1930	T3, 1930	L4, 1930	L5, 1930	L7, 1929	Mixture of *tritici*, 1930	Mixture of *levis*, 1930	Mixture of 1–5, 12–14, inclusive, 1931	
Turkey	2,546	7,366	0.7	0	0	0	0	0	0	0	—	.1
Hohenheimer	2,577	11,459	0	0	0	0	1	0	0	0	0	.1
Jenkin x Ridit	2,807	10,081	0	1	0	0	0	0	0	0	0	.1
Crimean	2,670	—	—	3	3	0	0	—	0.8	2	—	2
Ridit	2,324	6,703	0	3	0	3	2	0	3	0	—	2
Turkey x Florence	2,472	—	0	3	0	2	6	0	0.9	3	2	2
Turkey x Florence	2,471	10,080	0	2	0	5	8	0.2	0.7	3	1	3
Oro	2,550	8,220	3	0.6	0	0.6	0	3	0	6	3	2
Ridit x Bluestem	2,324/265	—	0	0	0.6	5	9	0	0	1	5	3
Heils Dickkopf	2,578	11,461	2	3	2	2	10	3	3	0	4	4
Hussar x Selection C	2,312/2,425	—	0	0.9	3	3	0	0.4	8	4	8	4
Argentine	2,764	10,061	—	7	0	3	10	—	4	2	—	6
Hohenheimer	2,579	11,458	0.5	3	0	0	3	0.4	0	0	29	5
Furst Hatzfeld	2,580	11,460	4	3	0.6	6	16	2	3	3	9	7
Ridit x Bluestem	2,841	—	0	0.7	0	32	19	12	0.8	14	18	14
Hussar x Aegilops	2,312/A.F.	—	0	17	0	49	6	6	12	32	9	19
Hussar x Aegilops	2,312/A.F.	—	0	25	11	40	6	15	8	16	64	27
Hussar	2,312	4,843	0	49	0	73	0	18	27	45	—	36
Stepnetshka	2,587	—	7	36	16	53	37	7	24	44	36	38
Cooperatorka	2,586	—	0.9	72	63	54	0	8	49	61	46	52
Martin	1,092	4,463A	0	41	81	85	3	19	30	67	—	56
Albit	2,517	8,275	0	89	58	79	0	39	59	71	—	67
White Odessa	2,308	4,655	0	72	72	88	0	70	56	59	—	71
Fortyfold	351	6,176	48	73	38	60	63	39	53	77	—	77
Turkey	326	6,175	6	83	0	86	77	74	57	74	—	78
Hybrid 128	592	4,512	65	79	54	85	84	59	76	84	90	100
Triplet	597	5,408	67	84	84	84	86	55	85	87	—	108

REACTION OF HOHENHEIMER X WHITE ODESSA F_3 PROGENIES TO THREE PHYSIOLOGIC FORMS OF BUNT

Studies on the inheritance of reaction of wheat to bunt have been reviewed recently by Aamodt (1) and Smith (8). Since then Churchward (2) has described inheritance in a cross between Florence and Hard Federation; a single factor difference in reaction to bunt between the two wheats was demonstrated.

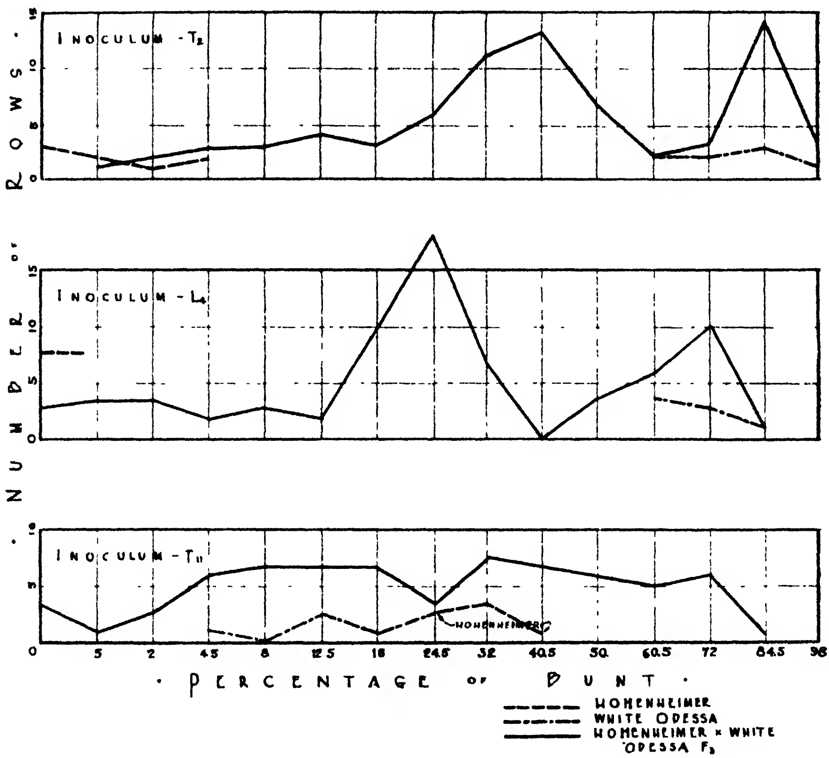

FIG. 1.—Distribution in percentage of bunt of F_3 progenies of Hohenheimer x White Odessa and rows of parents in series inoculated with T2, L4, and T11, respectively.

In 1928 a cross was made between Hohenheimer (C. I. 11459) and White Odessa (C. I. 4655), and the F_1 plants were grown in 1929. The F_2 generation, protected from the bunt organism by copper carbonate, was grown in 1930. All heads from each F_2 plant were collected at harvest. From each of 74 F_2 plants three samples of 75 seeds were counted out; one sample was inoculated with L4, another with T2, and the third with T11. The three series were sown in rod rows in the fall of 1930 with check rows after each 10 progeny rows.

As is shown in Table 4, Hohenheimer is highly resistant to T2 and L4 and moderately resistant to T11. At harvest the percentage of bunt in each row was determined by methods already described (8). The number of rows in the three series along with that of the parents

TABLE 4.—*Percentage of bunt on parents and F_3 progenies of Hohenheimer x White Odessa when inoculated with different physiologic forms of bunt.*

Variety or cross	Number of rows in bunt classes from 0 to 100%															Total No. rows
	0	Trace –1	1.1–3	3.1–6	6.1–10	11–15	16–21	22–28	29–36	37–45	46–55	56–66	67–78	79–91	92–100	
T2																
Hohenheimer	3	2	1	2												8
White Odessa . . .												2	2	3	1	8
F_3		1	2	3	3	4	3	6	11	13	7	2	3	14	2	74
L4																
Hohenheimer . . .	8															8
White Odessa. . . .												4	3	1		8
F_3.	3	4	4	2	3	2	10	18	7	0	4	6	10	1		74
T11																
Hohenheimer. . . .								3	4	1						8
White Odessa				1		3	1	3								8
F_3.	4	1	3	6	7	7	7	4	8	7	6	5	6	1		72

is presented in Table 4 and illustrated graphically in Fig. 1. The percentage of bunt has been divided into 15 classes in which each class from 0 increases by an arithmetical progression of 1. This spreads the variation of the resistant parent over approximately the same number of classes as the susceptible one. (See reaction to T2.)

Mention has been made of the fact that the reaction of Hohenheimer to L4 is similar to its reaction to T2. There is also little difference in the reaction of White Odessa. In Fig. 1 the reactions of the F_3 progenies to T2 give a curve very similar to that given by the progenies to L4. The amount of bunt on both parents and progenies with T2 is somewhat greater than that in the L4 series. The latter series was sown 2 days before the other and the difference in environmental conditions may be responsible for the difference in the amount of bunt.

A single factor difference between the parents in reaction to bunt is suggested by the curves of the reactions of the progenies. Further evidence, however, can be obtained from the correlation surface of the reaction of parts of each progeny to T2 and L4. This correlation appears as Table 5.

TABLE 5.—*Correlation between the percentage of bunt from forms T2 and L4 in the F_3 progenies of Table 4.*

L4 Bunt Classes \ T2 Bunt Classes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Σ
1	1	1	1												3
2		1	1	1	1										4
3			1	2	1										4
4					2										2
5						1	1	1							3
6						1			1						2
7							2	4	2	1	1				10
8						1	1	5	7	4					18
9							2	1	3	1					7
10															0
11										1			2	1	4
12												1	5		6
13											1	2	6	1	10
14													1		1
Σ	1	2	3	3	4	3	6	11	13	7	2	3	14	2	74

$r = 0.93 \pm .01.$

It is evident from Table 5 that a high correlation exists between the reaction of the progenies to T2 and L4, the value of r being $0.93 \pm$

0.01. It may be concluded from the distribution not only that a single factor determines the resistance of Hohenheimer to T2 and to L4, but also that the same factor is responsible for the reaction to the two forms.

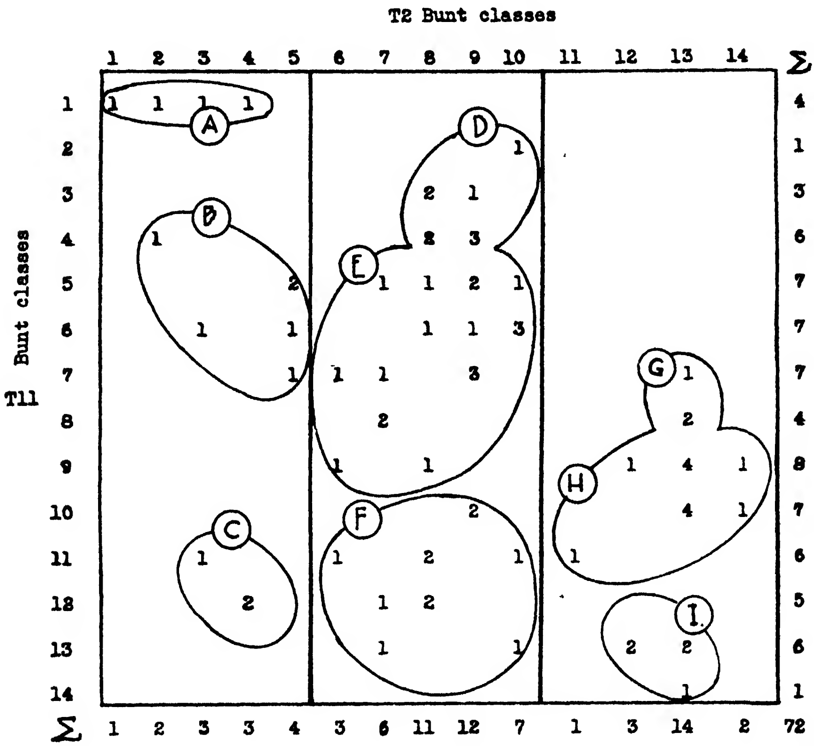

FIG. 2.—Correlation between the percentage of bunt in two portions of each of 72 F_3 progenies of Hohenheimer x White Odessa, inoculated with physiologic forms T2 and T11. $r = 0.42 \pm .07$.

An entirely different picture is seen in the reaction of parents and progenies to T11. White Odessa is moderately resistant to this form, and somewhat more resistant than Hohenheimer. The distribution of the reactions of parents and progenies to T11 (Fig. 1) indicates transgressive segregation. The factors involved can be determined more readily in the correlation surface of T11 with one of the forms examined above, e. g., T2. This correlation surface appears as Fig. 2.

The coefficient of correlation, $r = 0.42 \pm 0.07$, indicates that the factor in Hohenheimer for high resistance to T2 is responsible for the resistance of Hohenheimer to T11, because White Odessa is susceptible to the first, and moderately resistant to the latter.

The distribution of progenies in their reaction to T11 as shown in Fig. 1 suggests that not more than two factors determine the reaction to this form. One factor must be contributed by Hohenheimer and the other by White Odessa. Because of the correlation coefficient

of 0.42 ± 0.07, the Hohenheimer factor for resistance to T11 must be the same as or closely linked with the factor for resistance to T2 and L4. It is, however, highly probable that the one main factor in Hohenheimer determines its moderate resistance to T11 as well as its strong resistance to L4 and T2.

The effect of these factors should be apparent in the grouping of progenies in Fig. 2 in which the reaction of each progeny to T11 is correlated with its reaction to T2. It has been shown that a single main factor governs the reaction to T2. The correlation surface in Fig. 2 can therefore be divided into three portions, the first comprising the T2 arrays 1–5, the second the arrays 6–10, and the third the arrays 11–14. The three portions contain, respectively, progenies resistant, heterozygous, and susceptible to T2 as determined from Table 4. Since every progeny in each portion has the same Hohenheimer factor for resistance, the grouping of progenies within each portion must be dependent on the White Odessa factor. In the portion resistant to T2 there are three distinct groups in the ratio of approximately 1:2:1. In each of the other two portions there are two well-defined groups each in the ratio of approximately 3:1. The numbers of progenies in these groups are compared in Table 6 with those expected from a dihybrid segregation. The value of P = 0.89 indicates a very good fit. If the Hohenheimer factor for resistance is A and the White Odessa factor is B, then the genotypic constitution of the groups is as listed in Table 6. Furthermore, because the White Odessa factor for resistance to T11 is somewhat stronger than the Hohenheimer factor, the relative resistance of the groups to T11 should be in the order listed in column 3 of Table 6. Group C is the only one that does not conform to this grouping. The constitution AAbb indicates that this group should have the same reaction to T11 as Hohenheimer. In Table 4, Hohenheimer is distributed through classes 8–10 and not through classes 11 and 12 as is group C. The

TABLE 6.—*Test for goodness of fit to a dihybrid ratio of 72 F_3 progenies of Hohenheimer x White Odessa in reaction to T11.*

Group	Genotype	Order of resistance to T11	o Observed	c Calculated	o-c	$(o-c)^2$	$\frac{(o-c)^2}{c}$
A	AABB	1	4	4.5	0.5	0.25	0.056
B	AABb	3	6	9	3	9	1
C	AAbb	7	3	4.5	1.5	2.25	0.5
D	AaBB	2	9 } 28	27	1	1	0.037
E	AaBb	4	19				
F	Aabb	8	11	9	2	4	0.444
G	aaBB	5	3 } 15	13.5	1.5	2.25	0.167
H	aaBb	6	12				
I	aabb	9	5	4.5	0.5	0.25	0.056
			P=0.89		X^2=2.260		

number of progenies in the group, however, is small, and modifying factors may account for this discrepancy. Group G, the group having the same constitution as White Odessa, falls in the same classes as the White Odessa parent. The four very resistant and five very sus-

ceptible progenies from a total of 72 confirm the interaction of two factors in this correlation surface

SUMMARY AND CONCLUSIONS

Eleven fall-sown and 15 spring wheats (Tables 1 and 2) were used in differentiating five physiologic forms of *T. tritici* and at least two forms of *T. levis* obtained from collections of bunt made in the Pacific Northwest.

The reactions of 27 winter wheats, including the more important commercial varieties of this area, to single cultures and mixtures of these forms are described.

Hohenheimer is highly resistant to physiologic forms T2 and L4 to which White Odessa is quite susceptible. Hohenheimer and White Odessa, both winter wheats, are moderately resistant to T11

The seed obtained from each F_2 plant of a cross between Hohenheimer and White Odessa was divided into three parts; one part was inoculated with T2, another with T4, and the third with T11.

The factor in Hohenheimer for strong resistance to T2 is also responsible for the strong resistance to L4. The same factor also induces the moderate resistance of Hohenheimer to T11.

In the reaction of progenies to T11, well-marked transgressive segregation was observed, some progenies being much more resistant and some much more susceptible than either parent.

A single main factor, different from the factor for resistance in Hohenheimer, determines the moderate resistance of White Odessa to T11.

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THE AVAILABILITY OF HYDRATED LIME, LIMESTONE, AND DOLOMITE OF TWO DEGREES OF FINENESS, WITH SUPPLEMENTS OF RED CLOVER HAY, AS MEASURED BY LYSIMETER LEACHINGS[1]

W. H. MacIntire, K. B. Sanders, and W. M. Shaw[2]

The sustained beneficial effects of liming materials in a well-buffered soil are dependent upon the availability of the added materials after they become fixed as a part of the soil system. This factor is reflected by plant-ash components, and it is also registered by the composition of lysimeter leachings from fallow soil. The finer limestone separates are fixed by the soil more rapidly, but since the cost of limestone increases with the fineness of the product, it is not economical to prescribe an unnecessary degree of fineness. There is also a marked difference between the solubilities of limestone and dolomite, and it is therefore important to know just how fine these two rocks should be ground to insure fixation comparable to that found for the more soluble caustic forms of liming materials.

Previous contributions (3, 4)[3] gave the recoveries, carbonate residues, and fixations from four separates of limestone and of dolomite and their composites, as influenced by depth of incorporation. The influence of season upon speed of disintegration in full-depth incorporations was likewise considered (5). It appeared that, beyond a certain point, the degree of fineness may be a factor of no great economic significance. In the present 4-year lysimeter study, full-depth incorporations of limestone and dolomite of 40- to 50- mesh and 100- to 200-mesh fineness were compared with hydrated lime, with and without supplements of dried red clover at two rates. The main object was to determine whether any material advantage results from reduction of fineness beyond 40- to 50-mesh, for either type of limestone and the further effect of added green manure upon the outgo of bases and biological end-products.

EXPERIMENTAL

SOIL AND TREATMENT

The five additions of liming materials were incorporated with the full 8-inch depth of a Cumberland clay loam in lysimeters 1 foot deep. The soil, which showed a pH value of 6.1, had been in sod for more than 30 years, and it was therefore unusually well supplied with exchangeable bases, as shown in Table 1. The liming materials were used at the constant equivalent rate of 2,000 pounds of CaO for

[1]Contribution from the Department of Chemistry, University of Tennessee Agricultural Experiment Station, Knoxville, Tenn. Published with the approval of the Director. Received for publication August 15, 1932.

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[3]Reference by number is to "Literature Cited," p. 296.

2,000,000 pounds of soil. The hydrated lime and limestone carried 98.0% $CaCO_3$ ≎ and 1.25% $MgCO_3$ ≎. The dolomite contained 52% $CaCO_3$ and 37.5% $MgCO_3$. The limestone and dolomite that passed a 40-mesh sieve and stopped on a 50-mesh sieve and that passing a 100-mesh and stopping on a 200-mesh were washed free of adhering dust. Each treatment was duplicated and the results from the 18 pairs of tanks were averaged. The red clover hay was cut and dried spontaneously. The rainfall for the 4 consecutive years was 43.25, 60.18, 44.80, and 70.53 inches, the precipitation responsible for each collection of leachings being shown in Fig. 1. Because of prevailing rainfall, the soil could not be removed from the tanks exactly at the end of 4 years and the last period was therefore 13 months. Each of the periodic collections of leachings was analyzed for alkalinity due to carbonates plus bicarbonates and for pH values and nitrate content. The total calcium, magnesium, potassium, and sulfate determinations were made only upon annual composites.

CARBONATE RESIDUES

The soil from each of the 18 pairs of tanks was analyzed for carbonates at the end of the experiment. There was no residue of carbonates in any case. From a number of parallels with the finer materials, it is certain that the full additions had become entirely disintegrated during the first year, and for the most part during the first 6 months.

LEACHING OUTGO

Soluble organic matter.—It was planned to determine the influence of the added clover hay upon the amounts of dissolved organic matter carried in the percolates. It was found that the amounts present were so small and constant as not to justify continuing the determinations.

TABLE 1.—*Acid-soluble and exchangeable bases in Cumberland clay loam.*

Base	Acid-soluble* bases %	Exchangeable† bases %
Calcium as $CaCO_3$≎	0.256	0.193
Magnesium as $CaCO_3$≎	0.645	0.042
Potassium, K_2O	0.285	0.031

*1.115 HCl digestion.
†Hissink extraction method with normal NH_4 Cl.

Carbonate plus bicarbonate.—The leached bases that may be accounted for jointly as carbonates plus bicarbonates are shown in Table 2. The carbonates and bicarbonates were determined by both direct and double titrations to determine the amount of dissolved carbon dioxide. Almost invariably the proportion of CO_2 to $CaCO_3$ showed that both carbonates and bicarbonates were present in the leachates of low CO_2 concentration. The pH values of the unlimed controls consistently ran ± 7.0, but the leachings from the limed tanks were generally 7.1 to 7.2, with an occasional reading of 7.4 to 7.5.

Table 2.—*Influence of clover incorporation upon the carbonate plus bicarbonate outgo from hydrated lime and two finenesses of limestone and of dolomite* during a 4-year period, expressed in terms of $CaCO_3$ equivalence in pounds per 2 million pounds of soil.*

Year	Controls			Hydrated lime			Limestone						Dolomite					
							100-mesh			40 to 50-mesh			100-mesh			40 to 50-mesh		
	Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover	
		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons
1st	175	218	214	293	250	291	389	378	473	344	286	384	303	310	368	247	236	271
2nd	188	209	224	247	235	251	316	264	300	283	268	332	294	297	317	279	304	390
3rd	63	72	76	68	82	87	84	87	99	80	81	93	84	83	104	81	88	116
4th	199	217	209	218	245	246	255	228	278	244	226	266	239	255	256	264	246	287
Total	625	716	723	826	812	875	1,044	957	1,150	951	861	1,075	920	945	1,045	871	874	1,064

*Constant equivalence of 2,000 pounds of CaO.

The average outgo from the 24 limestone and dolomite tanks, when varying fractions of the added carbonates were present during a part of the first year, was 332 pounds against 304 pounds and 254 pounds, respectively, during the third and fourth years, when the carbonate forms were derived solely from the hydrolysis of the fixed calcium and magnesium. The decided drop during the third year of dispersed rainfall and minimal percolation conforms to the diminished losses of total calcium, magnesium, potassium, and sulfates for the same period. The large increments of organic matter did not give material and consistent increases in the outgo of carbonates, but, in general, the 8-ton supplements produced carbonate leachings greater than those found for the 2-ton supplements.

Total calcium and magnesium.—The recoveries of calcium and magnesium by annual periods, the totals of Ca + Mg, and the proportions accounted for other than as carbonates and bicarbonates are given in Table 3. The $CaCO_3$ equivalences of the calcium carried by the 2-ton and 8-ton clover additions were 126 pounds and 504 pounds, respectively; 68 pounds and 272 pounds being water-soluble. The corresponding increments of total magnesium were 44 pounds and 176 pounds, respectively; 33 pounds and 132 pounds being water-soluble.

In each case the maximal outgo of calcium was obtained during the first year and the minimal during the third year. The recoveries of calcium from the unsupplemented hydrated lime and the two finenesses of limestone were in close agreement. The enhancement in calcium outgo from the dolomite controls averaged 44% of that found for the three unsupplemented high-calcic additions. In each case the generation of CO_2, sulfates, and nitrates from the clover additions increased the outgo of calcium for each annual period, but a large fraction of the enhanced outgo from the clover controls can be accounted for by the calcium content of the clover. The enhancements of the first year were uniformly maximal. This was due in part to the ready solubility of the calcium content of the red clover hay. Hence, for both the high-calcic and dolomitic additions, the increases in calcium outgo induced by the 8-ton additions of clover were materially greater than those induced by the 2-ton additions. The outgo of calcium from each of the two limestone separates was greater than that from the hydrated lime, where supplements of clover were used. The average proportion of calcium in the increased Ca plus Mg outgo from the four dolomite-clover treatments was 44.3%, whereas that found for the unsupplemented dolomite controls was only 29%.

The outgo of magnesium was decreased by the additions of both hydrated lime and high-calcic limestone when used alone and also with clover at both rates, in harmony with previous findings relative to reciprocal repression (7). The enhancements in magnesium outgo from the clover controls are somewhat greater than the amounts carried by the clover additions, and the greater availability of the 100-mesh dolomite is more definitely recorded. This was noted especially during the first year.

Because of the repressive effect of the added calcic materials upon magnesium outgo and the enhanced outgo of magnesium from the added dolomite, an adequate comparison between the limestone and

TABLE 3.—*Influence of clover incorporation upon the outgo of calcium and of magnesium as carbonates and as nitrates and sulfates from hydrated lime and two finenesses of limestone and of dolomite* during a 4-year period, expressed in terms of $CaCO_3$ equivalence in pounds per 2 million pounds of soil.*

Year	Un-treated soil	Ground clover		Hydrated lime			Limestone						Dolomite					
					With clover		100-mesh			40 to 50-mesh			100-mesh			40 to 50-mesh		
								With clover			With clover			With clover			With clover	
		2 tons	8 tons	Alone	2 tons	8 tons	Alone	2 tons	8 tons	Alone	2 tons	8 tons	Alone	2 tons	8 tons	Alone	2 tons	8 tons
								Calcium										
1st	674	892	1,333	1,005	1,156	1,624	1,011	1,346	1,895	945	1,112	1,710	768	899	1,381	745	831	1,378
2nd	377	423	481	597	708	697	651	716	726	639	653	735	499	519	583	502	525	572
3rd	281	245	287	403	373	430	349	421	439	422	440	427	341	304	320	285	347	333
4th	344	331	401	451	476	537	480	479	489	509	551	506	378	390	363	364	387	387
Total Ca	1,676	1,891	2,502	2,456	2,713	3,288	2,491	2,962	3,549	2,515	2,756	3,378	1,986	2,112	2,647	1,896	2,090	2,670
								Magnesium										
1st	306	368	519	270	306	431	261	335	455	300	372	509	576	685	959	416	481	729
2nd	157	169	208	155	166	172	174	164	164	155	144	166	370	374	372	373	403	403
3rd	105	87	139	95	91	108	82	91	99	85	89	91	194	206	208	223	264	250
4th	151	172	161	141	140	144	142	138	137	141	152	136	275	277	243	294	312	300
Total Mg	719	796	1,027	661	703	855	659	728	855	681	757	902	1,415	1,542	1,782	1,306	1,460	1,682
Total Ca and Mg, 4-year period*	2,395	2,687	3,529	3,117	3,416	4,140	3,150	3,690	4,404	3,196	3,513	4,280	3,413	3,654	4,378	3,202	3,550	4,352
Ca and Mg as carbonates and bicarbonates	625	716	723	826	812	875	1,044	957	1,150	951	861	1,075	920	945	1,045	871	874	1,064
Ca and Mg as nitrates and sulfates	1,770	1,971	2,806	2,291	2,804	3,265	2,106	2,733	3,254	2,245	2,652	3,205	2,493	2,709	3,333	2,331	2,676	3,288

*Constant equivalence of 2,000 pounds of CaO.

dolomite separates can not be made without consideration of the respective sums of the outgo of calcium and magnesium, as given in Table 3. The rainwater content of calcium and magnesium was determined, but this increment was considered as being cared for in the outgo from the controls.

The most convincing comparisons as to the availabilities of the five additions, alone and with clover hay, are those for the Ca plus Mg outgo during the first year. For the unsupplemented materials, the recoveries from hydrated lime and the two finenesses of limestone were practically identical. For the 2-ton additions of clover hay, the largest outgo was from the 100- to 200-mesh limestone, whereas the outgo from the 40- to 50-mesh product was only 22 pounds in excess of that from hydrated lime. With the 8-ton clover hay supplement, the outgo from the hydrated lime was less than that found for either of the two limestone separates. When the dolomite was used alone, the Ca plus Mg outgo from the 100- to 200-mesh material was greater than that from either of the three high-calcic products, whereas the 40- to 50-mesh separate was 100 pounds less. When supplemented with 2 tons of clover hay, the 40- to 50-mesh dolomite lagged behind the near-equal recoveries obtained from the hydrated lime and the 40- to 50-mesh limestone, but the recovery from the 100- to 200-mesh separate exceeded the recoveries obtained from both the hydrated lime and the 40- to 50-mesh limestone. Where the 8-ton clover hay supplements were used, the combined calcium and magnesium from each of the two dolomite separates was in excess of that found for the hydrated lime, the two 100-mesh products giving practically identical totals that exceeded the outgo from the 40- to 50-mesh dolomite by 238 pounds.

The 4-year totals of Ca plus Mg for the unsupplemented high-calcic materials were in close agreement among themselves, their average being slightly less than the 3,202-pound outgo from the 40- to 50-mesh dolomite. The largest quantity came from the 100-mesh dolomite, which is accounted for by the fact that the fixed magnesium is more readily hydrolyzed than the fixed calcium. The 821-pound average enhancement in the total Ca plus Mg outgo from the five unsupplemented liming additions for the 4-year period was 23% of the added equivalence of $CaCO_3$. The increases in total Ca plus Mg from the 2-ton and 8-ton clover controls for the 4-year period were 122 pounds and 454 pounds more than the amounts supplied by the respective clover additions. With the 2-ton clover additions, the highest total Ca plus Mg values, and comparable results, were obtained from the two 100- to 200-mesh products, with a small difference shown for the 40- to 50-mesh materials, each of which gave a recovery in excess of that found for hydrated lime. With the 8-ton clover supplements, both the carbonate and the total Ca plus Mg recoveries from the four limestone separates were comparable among themselves and uniformly in excess of those found for the hydrated lime. Of the average enhancement of 821 pounds of total Ca plus Mg outgo from the five unsupplemented liming additions for the 4-year period, 64% was due to nitrates and sulfates. The average enhancement in total Ca plus Mg outgo induced by the 2-ton clover hay

supplement from the five treatments was 877 pounds, as against 292 pounds for the no-lime clover control. That found for the five lime additions with the 8-ton supplement was 782 pounds, whereas the enhancement shown for the 8 tons of clover without lime was 1,134 pounds.

From the comparisons between totals and carbonate recoveries it is evident that in each case the enhancement in Ca plus Mg outgo was due, in the main, to nitrates and sulfates. The order of magnitude in the annual outgo for both total Ca and Mg and carbonates is the same, the minimum being uniformly found in the third year. The results show interesting parallels with the 8-year results of Ellett and Hill, as reported by Drinkard (1), for the same type of soil with and without red clover hay supplements.

Sulfates.—The total sulfate outgo from each unsupplemented lime treatment was considerably greater than that from the untreated soil (Table 4). All of the liming materials induced increases in the outgo of sulfates from the clover without any marked difference in their capacity to affect this result. The several averages show that the enhancements were attributable primarily to the leachings of the first year. The results for the fourth year were uniformly higher than those for the second and third years, but the average recoveries from additions were identical to those found for the respective controls. The average recovery from the five lime additions with the 2-ton clover supplements was 41 pounds less than that found for the 8-ton supplements. The 2-ton and 8-ton clover additions supplied 29 pounds and 116 pounds of SO_3, respectively, of which 23 pounds and 92 pounds were water soluble. The 8-ton clover control gave up 40% of the increment supplied by it, but no increase in the ultimate sulfate outgo was found for the 2-ton supplement without lime. The average enhancement in the outgo of SO_3 from the five liming additions plus 2 tons of clover above the average for the liming materials alone was only 2 pounds more than the amount of SO_3 supplied by the clover. A like comparison for the 8-ton clover supplements gave an average recovery of 72 pounds of SO_3, or 62% of the increment. Using the same type of soil and with an average annual rainfall of 38.63 inches for the 6-year period, 1922–1928, Ellett and Hill (2) found an increase of 34.8 pounds of S as the average for seven liming materials at the rate of 2 tons $CaCO_3$ equivalence. With 12-ton supplements of red clover hay for the same liming materials, the average enhancement in outgo of sulfur was 39.7 pounds. The data as to enhanced outgo of sulfates from the unsupplemented liming materials are also in accord with previous results from the Tennessee Station (6).

Nitrates.—The initial nitrogen content of the soil was 0.150%. The 2-ton and 8-ton supplements gave increments of 118 pounds and 472 pounds, respectively. The first 4-month period after placement was exceedingly dry and the nitrification during that period was uniformly high. As shown in Table 5, none of the five single unsupplemented liming treatments caused any distinct increase in nitrate outgo above that from the untreated controls during the first year, although the 4-year total for each liming material exceeded that from

TABLE 4.—*Influence of clover incorporations with hydrated lime and two finenesses of limestone and of dolomite* upon the outgo of sulfates during a 4-year period, expressed in terms of SO_3 per 2 million pounds of soil.*

Year	Controls			Hydrated lime			Limestone						Dolomite					
							100-mesh			40 to 50-mesh			100-mesh			40 to 50-mesh		
	Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover	
		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons
1st	128	140	147	194	203	209	191	201	232	175	181	199	190	195	221	160	176	200
2nd	117	111	123	107	120	128	111	121	126	122	134	151	116	125	134	130	148	192
3rd	67	65	76	91	89	99	86	96	108	99	107	104	98	103	110	100	112	121
4th	163	158	175	171	165	179	158	167	162	169	169	156	163	176	152	164	163	170
Total	475	474	521	563	577	615	546	585	628	565	591	610	567	599	617	554	599	683

*Constant equivalence of 2,000 pounds of CaO.

TABLE 5.—*Influence of clover incorporations with hydrated lime and two finenesses of limestone and of dolomite* upon the outgo of nitrate during a 4-year period, expressed in terms of N in pounds per 2 milliom pounds of soil.*

Year	Controls			Hydrated lime			Limestone						Dolomite					
							100-mesh			40 to 50-mesh			100-mesh			40 to 50-mesh		
	Soil alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover	
		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons
1st	212.6	268.4	406.1	200.5	290.2	420.2	227.3	269.2	462.1	202.9	285.5	451.0	207.5	276.9	454.5	224.4	265.5	449.6
2nd	79.1	103.0	106.8	98.9	138.2	141.7	102.0	134.3	149.1	95.2	109.9	148.0	113.8	119.9	124.4	108.9	108.5	110.4
3rd	72.8	62.3	77.1	82.3	81.7	99.2	65.4	86.4	92.6	81.7	90.1	84.6	88.2	81.6	83.9	77.3	96.8	89.8
4th	70.3	64.3	74.8	70.8	72.6	92.1	69.9	76.1	73.6	79.6	86.7	77.0	68.3	75.8	73.8	72.1	78.9	75.4
Total	434.8	498.0	664.8	452.5	582.7	753.2	464.6	566.0	777.4	459.4	572.2	760.6	477.8	554.2	736.6	482.7	549.7	725.2

*Constant equivalence of 2,000 pounds of CaO.

the controls. For both the 2-ton and 8-ton clover additions without lime, the recoveries of nitrogen were about one half the amount added. There was an enhancement in the nitrate outgo from the unsupplemented clover additions at both rates during the first year, but the liming materials did not produce further consistent increases. The results from the limestone and the dolomite of the two finenesses were in close agreement and the eight unsupplemented limestone and dolomite additions were compared with the eight additions with clover at each of the two rates against the two-tank averages for the untreated soil, the 2-ton and 8-ton clover controls, and the hydrated lime alone and also with clover at both rates. The average enhancement in nitrogen outgo from the five lime additions with 2 tons of clover was 57% of the amount carried by the clover. The difference between the outgo of nitrogen from the 8-ton clover controls and that found as an average for the 10 tanks that received the clover and the five liming treatments was 86 pounds, or only 78.2% of the amount supplied by the clover. The cumulative outgo for these comparisons with the periodic rainfall that produced each collection of leachings is shown graphically in Fig. 1.

Potassium.—A comparison between the potassium leached from this soil (Table 6) and that leached from the same soil after cropping for 30 years (8) shows that there was a large accumulation of exchangeable potash in the present soil. This holds for each annual period, but it is especially marked during the first year. The increments of potassium from the 2-ton and 8-ton unlimed clover incorporations were 57.6 pounds and 230.4 pounds, respectively, and neither of these increments was recovered. The outgo of potassium from each of the five liming treatments was uniformly less than that obtained from the unlimed control, the average total being 120 pounds as against 155 pounds. The average outgo of 145 pounds of K from the 2 tons of clover and the five liming additions as against 194 pounds for the clover alone shows that the repressive effect of liming upon potassium outgo was still in effect upon the amount of potassium furnished by this clover supplement. With the heavier 230.4-pound increment of potassium from the 8-ton clover supplement, the repressive effect of liming on potassium outgo was less marked, since the clover supplement furnished *per se* an appreciable quantity of calcium and magnesium. That is, the 8-ton clover addition was, in a sense, a potash treatment and a light liming. In each of the 17 pairs of treatments, the outgo of the third year was decidedly less than that found for the other three annual periods. The average outgo from the 8-ton clover supplements with the five liming additions was 270 pounds as against 292 pounds for the clover alone. These results are in harmony with previous findings (8).

DISCUSSION AND SUMMARY

In applying the foregoing results obtained in a 4-year study with 18 pairs of lysimeters several points are to be considered. Commercial limestone and the home-ground products differ. The former is often a product consisting solely of finely ground material. The latter is generally a mixture of different finenesses, limited by the character of

rock as it affects tonnage per diem in grinding, wear on machinery, and ultimate cost. Since the commercial products are usually finer than the coarser separates used in the present experiment, the results

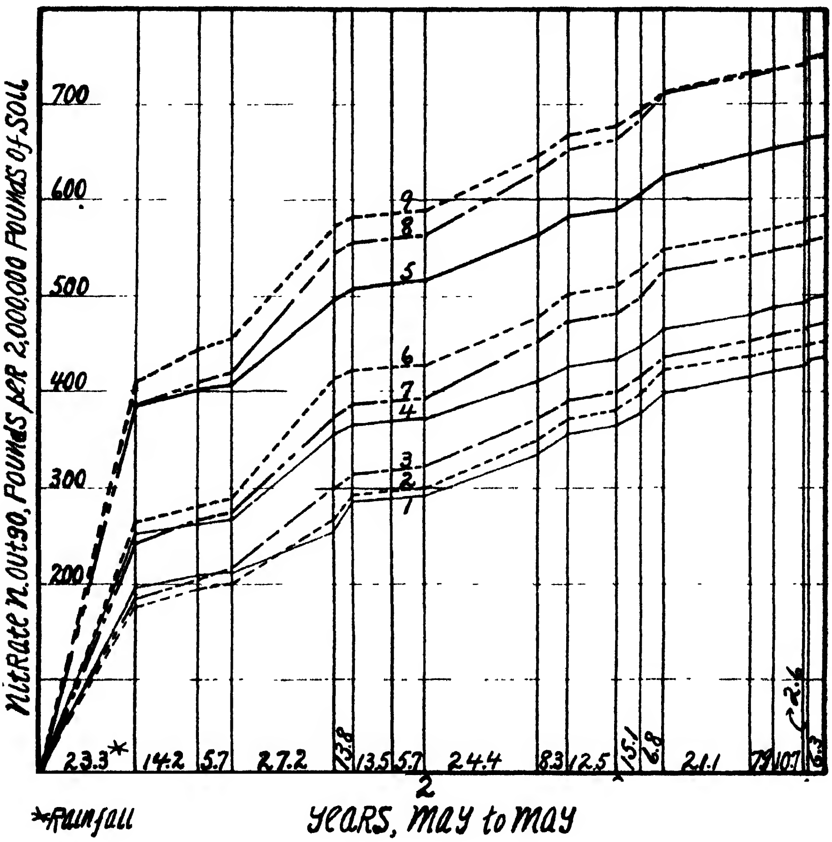

FIG. 1.—Periodic-cumulative 4-year outgo of nitrate nitrogen from a brown loam that received 2,000-pound CaO equivalent additions of hydrated lime, ground limestone, and dolomite of 100-mesh and 40- to 50-mesh fineness, with and without 2 tons and 8 tons of red clover hay, moisture-free basis, expressed in terms of pounds of nitrogen per 2,000,000 pounds of soil.

1. Average for two untreated controls. 2. Average for two hydrated lime additions. 3. Average for eight limestone and dolomite controls. 4. Average for two 2-ton clover controls. 5. Average for two 8-ton clover controls. 6. Average for two 2-ton clover additions with hydrated lime. 7. Average for eight 2-ton clover additions with limestone and dolomite. 8. Average for two 8-ton clover additions with hydrated lime. 9. Average for eight 8-ton clover additions with limestone and dolomite.

may be interpreted as applying directly for such products and for types of soil similar to the one used and under comparable climatic conditions. For a soil of good fixing capacity, even without marked acidity, the 100- to 200-mesh fineness of either limestone or dolomite is comparable to an equivalence of hydrated lime, when evaluated by

TABLE 6.—*Influence of clover incorporations with hydrated lime and two finenesses of limestone and of dolomite* upon the outgo of potassium during a 4-year period, expressed in terms of K in pounds per 2 million pounds of soil.*

Year	Controls			Hydrated lime			Limestone						Dolomite					
							100-mesh			40- to 50-mesh			100-mesh			40- to 50-mesh		
	Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover		Alone	With clover	
		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons		2 tons	8 tons
1st	59	92	158	45	54	120	46	57	142	48	65	121	43	59	130	54	50	146
2nd	33	50	80	32	45	75	30	44	75	28	34	64	28	42	81	27	42	84
3rd	34	22	23	20	22	23	15	22	25	14	13	24	20	19	26	16	21	22
4th	29	30	31	32	26	40	27	26	38	25	25	37	27	31	38	23	26	40
Total	155	194	292	129	147	258	118	149	280	115	137	246	118	151	275	120	139	292

*Constant equivalence of 2,000 pounds of CaO.

enhanced nitrification and sulfate generation, soluble Ca plus Mg, and repressive effects upon potassium solubility for the 4-year period. The same holds for the 40- to 50-mesh limestone. The 40- to 50-mesh dolomite is not so readily available during the first year, but the disparity is not great. Since the heavier types of soils of greater acidity would effect a disintegration more rapid and intensive than that found for the well-buffered, near-neutral soil used, it would follow that the fineness of 40- to 50-mesh is ample for such soils, especially if an appreciable period elapse between the incorporation and the seeding.

For sandy soils, however, it would be expected that the differences attributable to fineness would be greater than those found for the heavier type of soil. This would be especially true in case of the less soluble dolomite, which should be exceedingly fine when used in sandy soils.

Although the total amounts of soluble Ca plus Mg derived from the several dolomite additions were generally comparable to, though slightly in excess of, those found for the corresponding limestone addition, there was a distinct difference in the proportions of the two elements present in the free-soil water This is accounted for not only by marked enhancement of soluble magnesium derived from the dolomite, but also by the diminished outgo of native magnesium where the high-calcic materials were used. The red clover hay increased the outgo of calcium and magnesium, the largest changes being noted during the first year, but this increase was due, primarily, to the amount of soluble calcium and magnesium supplied by the red clover additions Hence, the addition of green manure did not appreciably increase loss of the Ca plus Mg supplied by the liming materials. As a close approximation, applying to all forms, one-fourth of the added liming materials was lost during the 4-year period. The several materials may be considered of comparable value in their tendencies to increase supplies of nitrates and sulfates.

When applied to home-ground limestone, the findings indicate that such a product may well be evaluated on the basis of the fraction that is of the fineness less than 40-mesh. The coarser fractions ultimately undergo disintegration, but for immediate use the evaluation should be on the fraction that would pass a 40-mesh sieve. As has been pointed out (3, 5), the factors of seasons and depth of incorporation are also to be considered.

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NOTES

SPONTANEOUS COMBUSTION ON WEED PLATS SPRAYED WITH A SOLUTION OF ATLACIDE

Chlorates, especially sodium and calcium, in recent years have been used extensively as chemical aids in weed control. With them has also come an increased fire hazard. Not infrequently does one read of accidents where someone has been seriously injured as a result of his clothing becoming ignited after spraying weeds with chlorates.

The Utah Agricultural Experiment Station, in cooperation with the State Department of Agriculture, has made extensive studies since 1929 on the possible use of chlorates in weed control. Since 1929 a large amount of both sodium and calcium chlorates have been used with little difficulty so far as fires have been concerned. However, on September 22, 1932, a fire, which might have been serious, broke out as a result of their use. This fire was purely a case of spontaneous combustion. Because of the possible seriousness of the problem, it appears desirable to submit a brief note giving an account of the incident.

During the forenoon of September 22, 1932, three plats (2/3 square rod) of Canada thistle (*C. arvense* L.) were sprayed with a solution of Atlacide.[1] The solution was made by adding 2 pounds of Atlacide to each gallon of water. This solution was applied at the rate of 1 gallon to the square rod. The chemical was applied between 10 and 11 a.m. Since it was an experiment which had been previously planned for three replications of each treatment, three separate plats were sprayed. These were treated within a period of 15 or 20 minutes of each other.

At about 12:30 p.m. a fire started on one of the plats, about 3 minutes later a fire started on the second plat; and about 20 minutes later on the third. In each case fire seemed to occur in only one localized area on the plat from which it spread until it was extinguished.

These weed plats were located in a bluegrass (*P. pratensis*) pasture, and at the time the chemical was applied there was a rather heavy undergrowth of dry bluegrass. The fire started in this dry undergrowth. Two of these burned areas are indicated in Fig. 1. Plats apparently burned in the order of dryness of the undergrowth rather than in the order of their treatment.

Since there was a sudden change in temperature and humidity just prior to the time the burning began, it was thought that this

[1]Commercial name for calcium chlorate.

FIG. 1.—The dark areas in foreground and background are the plats on which spontaneous combustion occurred. The light area in the center shows the condition of the undergrowth of bluegrass (*P. pratensis*) on the plat at the time burning began.

might be a contributing factor. During the forenoon of the day the treatments were made, it was cloudy part of the time and generally cool. However, just a few minutes before fire began on the first plat, the sun came out from behind the clouds, and for a time it appeared unusually hot as compared to the temperature during the forenoon. In order to determine more exactly this change in temperature and humidity, a hygro-thermograph chart was examined (Fig. 2).[2] The temperature and humidity records were made about 1.5 miles north of where the fire occurred. This chart indicates the sudden change in temperature and humidity on Thursday, September 22, 1932, at about 12:30 p.m. The temperature rose from 65° to 75° F, and the humidity dropped from 66 to 31%.

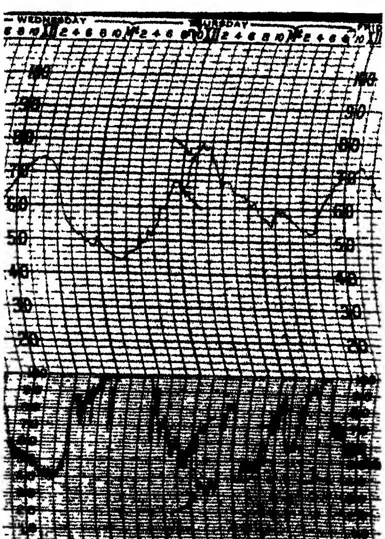

FIG. 2. — Hygro-thermograph, temperature above and humidity below. Note the sudden rise in temperature and lowering of the humidity at about 12:30 p.m. Thursday. (See arrows.)

Whether or not this sudden change in temperature and humidity was an important factor in causing the fire or whether it was coincident, is not definitely known. This cannot be determined by a single incident of

[2]The hygro-thermograph was furnished by Dr. L. H. Blood of the Utah Agricultural Experiment Station.

this nature and no attempt was made to reproduce the fires artificially. However, it does appear that the heavy undergrowth of bluegrass and the sudden change in temperature and humidity were probably important contributing factors. Otherwise, it would seem that spontaneous combustion would more commonly follow the use of chlorates.

Regardless of the underlying cause or causes of the fires on sprayed weed plats, the importance of caution when spraying weeds with this chemical cannot be too strongly emphasized. Especially is this true if spontaneous combustion occurs when spraying in the proximity of haystacks, buildings, mature grain fields, or on ranges and other places where serious loss may result.—D. C. TINGEY, *Utah Agricultural Experiment Station, Logan, Utah.*

SEASONAL VARIATION OF pH IN FIELD SOILS A FACTOR IN MAKING LIME RECOMMENDATIONS

Several soil investigators have observed seasonal variation in pH values of the soils taken from cultivated fields. In general, the acid soils have been found to be more acid in summer and the early fall than in winter and early spring. Variations of from 0.2 to 2.0 pH units have been observed.

To make lime recommendations for maximum crop production on the basis of the pH value of the soil without knowledge of the seasonal variation would lead one into considerable error. Particularly is this factor of special interest on soils with low buffer capacity on which truck crops are being grown. The reaction of these types of soils must be controlled within rather narrow limits in some instances.

A very uniform potato field of Sassafras sandy loam located at Onley, Va., has been divided into a number of plats in a lime experiment. There are over 10 check plats well distributed over the area. In a study of the effect of the different treatments of the soil upon their pH value, these check plats showed a seasonal variation in pH readings, the greatest difference being between the readings given in July and December, as indicated below:

	Normal pH of the soil	pH of soil leached free of easily soluble salts
	December 12, 1932	
Average*	5.14	5.48
Maximum variation	0.20	0.26
	July 12, 1932	
Average*	4.67	5.44
Maximum variation	0.37	0.16

*Average of 10 plats; a composite of 15 to 20 borings; 0–3⅓ inch horizon; quinhydrone procedure.

The above figures indicate a variation of about 0.5 of a pH unit with a possible variation of over 1 pH unit, e. g., from 5.5 to below 4.7. The difference in water-soluble mineral acids in the soil at these two seasons accounts for these variations, as shown below:

	Nitric acid, p. p. m.	Sulfuric acid, p. p. m.	Hydrochloric acid, p. p. m.	Ignition loss %
		December		
Average*.....	76	122	1.3	2.94
		July		
Average*.....	156	147	1.9	3.05

*Average of 10 plats; air-dried soil; all estimations made at the same time.

The rainfall, fertilization, and nitrification account principally for these variations. Although the rainfall is fairly evenly distributed over the year at Onley, the evaporation from the soil and plants is considerably greater in summer than in winter, which makes leaching of the soluble salts more prevalent in winter than summer.

The above data are offered as a suggestion to those making lime recommendations on the basis of the pH value of the soil. This problem is being extended and later will be reported upon in full.—JACKSON B. HESTER and FLORENCE A. SHELTON, *Virginia Truck Experiment Station, Norfolk, Va.*

AGRONOMIC AFFAIRS

THE CROPS SECTION PROGRAM

The program committee of the Crops Section announces that at the annual meeting of the Society in Chicago in November two of the three sectional meetings of the Crops Section will be devoted to papers which present results of recent original research. Investigators contemplating submitting papers for these meetings are requested to communicate their intentions to Dr. Merle T. Jenkins, Iowa Agricultural Experiment Station, Ames, Iowa, at as early a date as possible.

NEW AGRONOMIC JOURNALS

Announcement has been made by the Oxford University Press of the publication quarterly, beginning with April, 1933, of *The Empire Journal of Experimental Agriculture.* Dr. E. H. Tripp, formerly joint-editor of the *Journal of the Society of Chemical Industry*, has been appointed Secretary and General Editor of the new journal. Sir John Russell, Director of the Rothamsted Experimental Station, is chairman of the Editorial Board. The journal is intended to furnish an additional outlet to agricultural research workers in the Empire countries, and will report experimental work on the feeding and management of livestock, cultivation and manuring of crops, trials of farm machinery, agricultural economics, and experimental technic. The annual subscription (four numbers) rate is 20s. post free.

The *Bulletin de l'Institut Agronomique et des Stations de Recherches de Gembloux* is also being published quarterly at Gembloux, Belgium. The first number contains the following papers, among others: Results of Variety Tests with Wheat, by C. Journée and E. Larose; The Microbiological Examination of Soils, by G. Verplancke; The Sugar Beet Fly in Belgium, by R. Mayné and W. van den Bruel; and New Apparatus for Determining the Concentration of Hydrogen Ions, by G. Demortier.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 MAY, 1933 No. 5

THE CHEMICAL COMPOSITION AND GRADES OF BARLEY AND OAT VARIETIES[1]

D. D. HILL[2]

Barley and oats grown in the United States are used chiefly for the feeding of livestock. The evaluation of these grains, therefore, is a matter of interest to stockmen, farmers, and agronomists generally. The federal grades for oats and barley (1)[3] are used to indicate the quality of such grain as it enters into commerce. During recent years the question has been raised as to how accurately quality is reflected in the official grades. The grades are determined by an examination of physical factors, and the use of physical factors alone in the determination of quality undoubtedly has certain limitations. When oats and barley enter into a ration for livestock, standard analyses (6) are generally used to provide the proper nutritive ratio, but even here there is some question as to the accuracy of this practice. Is it not reasonable to suppose that varieties and types of grain will differ in composition even when grown under comparable conditions? Certainly this is true of wheat (5), and we have ample evidence that the composition of wheat is influenced to a marked degree by variation in the growth conditions (3, 9).

Dairymen in western Oregon reported difficulty in computing satisfactory rations when standard analyses (6) were used. This suggested the studies reported herein. Although the results obtained are not conclusive, they do suggest that some revision of our practices may be desirable. They suggest also that such variations as are found in these studies may well exist in other sections.

MATERIAL AND METHODS

Varieties of oats and barley grown in the field varietal trials at the Oregon Experiment Station were selected for analysis. The varieties selected were grown in two different years (1929, 1930) and on three different soil types, namely, Chehalis, a fine sandy loam

[1]Contribution from the Department of Farm Crops, Oregon Agricultural Experiment Station, Corvallis, Ore. Published as Technical Paper No. 182 with the approval of the Director. Received for publication August 15, 1932.

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[3]Reference by number is to "Literature Cited," p. 311.

underlain by gravel (8); Willamette, an upland silty loam soil of good fertility (2); and Amity, a rather heavy silty clay soil underlain by heavy clay subsoil (2).

Analyses were made of 46 oat varieties and 45 barley varieties by C. F. Whitaker, Department of Agricultural Chemistry, Oregon Experiment Station, under the supervision of J. S. Jones. These analyses show the crude protein, the ash, the crude fiber, the ether extract, and the moisture content. The moisture content ranged from 8 to 10% of the total original weight. The other factors shown by the analyses were computed on a dry matter basis and the total digestible nutrients were determined on the same basis according to the method of Henry and Morrison (6). The test weight and the grade of each sample were determined according to federal standards (1).

RESULTS AND DISCUSSION

The data on oat varieties given in Table 1 present some interesting comparisons. In comparing the analyses of spring oats with the standard analyses (6), significant differences are found in the lower protein content and the higher ether extract of the western Oregon oats. The percentages of ash and crude fiber are similar and the total digestible nutrient value is practically the same but on the average slightly higher.

The average analysis of oats given by Henry and Morrison and computed on a moisture-free basis shows the following percentages: Crude protein, 13.66; ether extract, 4.84; ash 3.85; crude fiber, 12.00; and total digestible nutrient, 77.50.

Some differences can be noted between varieties grown under the same conditions. The varieties grown on Amity soil in 1929 ranged in total nutrient value from 77.71% for the variety Madrid to 81.06% for the variety Kanota. Likewise, the varieties grown on Willamette soil in 1930 ranged from 76.23% for the variety Three Grain to 80.67% for the variety Joannette. The varieties grown on Chehalis soil in 1930 were lower in protein and in total digestible nutrients but higher in fiber on an average than the same varieties grown on Willamette soil in the same year. The high percentage of fat in the variety Markton distinguishes it from the other spring oat varieties. This variety had more than 7% fat and a total digestible nutrients value of 80.31% when grown on Willamette soil in 1930. Previous analyses indicate that Markton usually has a high fat content.

Differences in varietal composition were also noted by Hunter (7), but he does not believe they are sufficient to permit of economic discrimination. He states that yield is more important than composition. This is probably just as true in western Oregon as in England when spring oats are considered. The high yielding varieties Victory, Three Grain, and Eclipse will produce more pounds of total digestible nutrients per acre in western Oregon than such varieties as Joannette or Kanota despite the higher analysis of the latter varieties. When the comparison is made between winter and spring varieties, there is enough difference in composition to justify certain varietal discrimination.

TABLE 1.—*Percentage analyses of oat varieties grown on different soil types and in different years, computed on a moisture-free basis.*

Variety	Crude protein	Ether extract	Ash	Crude fiber	T.D.N.*	Test weight
Spring Oats on Amity Soil, 1929						
Victory	10.77	5.12	3.25	12.35	78.22	39.9
Idamine	11.89	5.29	3.44	12 78	78.04	38.7
Madrid	10.70	5.34	3.83	12.97	77.71	38.2
Abundance	10.42	5.56	3.15	12.39	78.79	37.3
Joannette	9.88	6.64	3.58	11.12	80.29	38.5
Favell	10.70	5.51	3.06	12.79	78.63	38.7
Eclipse	10.64	5.15	3.30	14.24	77.37	38.2
Senator	10.98	5.62	3.11	11.85	79.15	40.9
La Connor	9.90	5.31	3.80	11.16	78.56	41.5
White Russian	9.17	6.36	3.41	11.89	79.78	36.9
Kanota	13.58	6.92	3.45	10.15	81.06	38.7
Climax	12.40	5.42	3.30	11.70	78.77	38 6
Spring Oats on Willamette Soil, 1930						
Victory	8.17	5.24	3.75	13.13	77.69	39.9
Idamine	8.63	5.18	4 06	14.87	76.56	38.5
Madrid	9.23	5.53	4.11	12.44	78.01	37.5
Abundance	8.72	5.09	3.88	14.04	76.98	36.1
Joannette	10.60	6.51	4.05	9.10	80.67	37.0
Favell	8.97	5.51	3.75	13.73	77.70	37.7
Eclipse	9.54	5.46	3.88	14.06	77.37	37.9
Senator	9.25	5.26	3.88	13.24	77.52	37.3
La Connor	8.86	5.17	3.90	12 88	77.63	38.9
Three Grain	8.19	4.92	3.99	15.10	76.23	37.5
Golden Rain	9.26	5.44	4.04	13.05	77.68	38.5
Markton	9.01	7.09	3.88	11.77	80.31	38.3
Iogren	8.27	4.66	3.30	12.86	77.48	35.5
Victory Sel. No. 28	8.34	5.14	3.52	14.52	77.11	38.8
Victory Sel. No. 29	8.50	5.50	3.88	12.96	77.94	39.2
Rainbow	8.87	4.64	3.73	11.55	77.73	36.8
Wayne	9.61	5.96	4.01	12.97	78.32	36.7
Anthony	9.18	6.18	3.68	12.14	79.25	39.5
Star	9.17	4.97	3.81	12.44	77.60	38.1
Odal	9.29	5.50	4.02	12.27	78.11	41.4
Golden Rain II	7.98	5.17	3.97	13.62	77.21	38.5
Golden Rain	9.25	5.56	3.84	11.97	78.48	40.3
Spring Oats on Chehalis Soil, 1930						
Victory	8.20	4.91	4.36	13.18	76.79	41.4
Madrid	8.70	5.07	5.09	12.92	76.48	40.4
Favell	8.48	5.44	4.67	13.00	77.21	40.6
Three Grain	7.78	4.63	4.48	14.73	75.62	39.1
Winter Oats on Chehalis Soil, 1930						
Custis	12.30	7.38	3.76	9.56	81.65	41.8
Lee	12.27	7.76	3.71	9.08	82.36	42.5
Red Indian	12.22	6.82	4.43	11.68	79.49	39.0
Gray Winter Sel. No. 22	8.41	8.08	3.38	8.94	83.17	42.5
Gray Winter Sel. No. 20	8.26	8.15	3.34	9.00	83.25	39.9
Gray Winter Sel. No. 21	8.39	8.07	3.41	8.53	82.93	42.9
Gray Winter Sel. No. 23	11.22	8.29	3.93	9.65	81.74	40.9
Gray Winter	11.67	8.37	3.81	9.64	82.90	42.1

*Total digestible nutrients.

In contrast to the spring oat varieties, the analyses of winter oats are striking. In general, winter oats are high in protein. They are extremely high in ether extract and are low in fiber. As the ether extract has the nutritive value of 2.25 times that of the protein or the remaining nitrogen-free extract, the result is a high percentage of total digestible nutrients for the winter oat varieties. These analyses confirm the opinion of feeders that gray winter oats have a higher feeding value than the white spring oats. No data are available as to any difference in the digestibility of the material in winter and spring oats.

The difference between the nutrient value of winter and spring oats indicated in Table 1 is confirmed by the analyses of three varieties, *viz.*, Abundance, Victory, and Gray Winter, grown in England in 1921 (7).

These English varieties show little variation from Oregon oats in the ether extract and ash content. The percentages of crude protein for these varieties are 10.42, 10.77, and 11.67, and of total digestible nutrients 78.79, 78.22, and 82.80, respectively. Although these are slight variations from the analyses of the same varieties as reported in Table 1, the differences are small. According to Hunter (7), Gray Winter is always relatively low in protein, high in oil, and low in fiber. He states that these characteristics are associated with the long growing season of the fall-seeded varieties. The only variation from these conclusions as applied to Gray Winter oats grown in western Oregon is that the analyses show a relatively higher protein content.

The analyses of the barley varieties given in Table 2 show much less variation in composition than the oat varieties. There is also less variation in the total digestible nutrient value of barley than of oats. The variation in total nutrient value of the hulled barley was only 2.4%, ranging from 86.4 to 88.66% Of the 45 samples analyzed, 31 had total digestible nutrient values between 87 and 88%. Of the 45, two were hull-less. These hull-less varieties had total digestible nutrient values of 89.5 and 89.12%. Of the hulled barleys, Hannchen and other two-row barleys had the lowest percentage of fiber and the highest nutrient value.

The analyses of Oregon varieties of barley differ from the average analyses reported by Henry and Morrison mainly in a lower protein content The percentages of ether extract, ash, crude fiber, and total digestible nutrients are approximately the same.

Tables 3 and 4 were prepared to show the variation in composition under different seasonal and soil conditions. They show the nutrient value of samples grown more than one year or on more than one soil type. As the data are not complete and as there are some variations in results, conclusions can be indicated only. There are rather definite indications, for example, that the oats grown on Chehalis soil average lower in composition than when grown on Willamette soil. On the other hand, the differences are not great and on the other soil types are not always consistent.

TABLE 2.—*Percentage analyses of barley varieties grown on different soil types and in different years, computed on a moisture-free basis.*

Variety	Crude protein	Ether extract	Ash	Crude fiber	T.D.N.*	Test weight
Winter Barley on Chehalis Soil, 1929						
Orel	9.61	2.06	2.95	5.18	87.80	51.8
Tennessee Winter	9.15	2.35	2.79	6.02	87.94	42.7
Tennessee Winter Sel	9.61	2.12	2.56	5.92	87.92	50.4
Alaska	9.51	2.43	2.90	6.54	87.64	43.2
Pidor	8.27	2.29	2.74	6.11	88.04	48.5
O. A. C. No. 7	8.39	2.32	2.78	7.20	87.60	45.2
O. A. C. Sel. 2	8.55	2.28	2.63	7.23	87.71	47.0
O. A. C. Sel. 4	8.34	2.47	2.83	7.51	87.56	44.0
O. A. C. Sel. 6	8.61	1.89	2.93	6.76	87.24	45.7
O. A. C. Sel. 1	9.34	1.85	2.96	6.31	87.19	43.0
Wisconsin Winter	9.33	2.14	2.91	6.65	87.44	46.1
Winter Barley on Williamette Soil, 1930						
Orel	9.91	1.86	2.95	5.38	87.69	50.3
Tennessee Winter	9.27	2.28	2.92	6.39	87.58	47.0
Tennessee Winter Sel.	8.98	1.96	2.85	6.10	87.55	49.3
Alaska	9.93	2.19	2.90	6.45	87.42	45.8
Pidor	10.19	2.26	2.90	6.46	87.47	46.0
O. A. C. No. 7	10.99	2.50	2.96	6.59	87.49	49.9
O. A. C. Sel. 6	8.78	1.97	2.84	6.42	86.92	49.5
O. A. C. Sel. 1	8.98	2.18	2.74	6.42	87.74	47.0
Wisconsin Winter	10.12	2.08	3.03	6.70	87.13	46.7
Kroph	9.84	1.71	2.94	6.98	86.40	47.0
O. A. C. No. 7 (fall planted)	8.65	2.20	2.96	7.30	87.30	48.1
O. A. C. No. 7 (spring planted)	7.59	1.89	2.50	5.94	88.09	47.6
Spring Barley on Amity Soil, 1929						
Hannchen	9.77	2.23	2.14	4.83	88.58	48.0
Atlas	11.81	2.17	3.07	7.00	86.76	40.6
Ben Beardless	9.10	2.10	3.10	7.24	87.06	45.8
Montana 1583 (hull-less)	11.28	2.54	2.20	2.77	89.50	58.1
Peruvian	10.59	2.30	2.72	7.37	87.30	39.1
Trebi	9.86	2.17	2.69	5.60	87.95	49.4
Spring Barley on Chehalis Soil, 1930						
Hannchen	9.20	1.78	2.96	4.38	87.92	55.3
Ben Beardless	8.11	1.72	3.16	7.19	86.78	47.6
Peruvian	8.85	2.11	3.10	7.24	87.06	47.6
Trebi	8.44	1.87	2.91	6.01	87.57	50.1
O. A. C. No. 7	8.69	2.32	2.92	6.86	87.55	47.7
Spring Barley on Willamette Soil, 1930						
Hannchen	8.32	2.23	2.65	4.35	88.66	55.4
Ben Beardless	8.09	1.93	3.05	7.10	86.78	46.5
Peruvian	8.58	2.22	2.82	7.10	87.53	44.8
Trebi	8.09	1.86	2.77	5.75	87.77	48.2
O. A. C. No. 7	8.59	2.82	2.96	7.07	88.03	48.6
Advance Pedigree	8.95	1.99	2.70	5.61	87.85	50.4
Blue Hull-less	10.33	1.99	2.25	2.54	89.12	65.0
Victory	7.74	2.07	2.76	4.33	88.55	55.1
Orel	9.20	2.10	3.09	5.44	87.75	46.8
Hannchen (clover sod)	8.30	2.15	2.61	4.20	88.47	56.5

*Total digestible nutrients.

The analyses of oats presented in Table 3 show some variations in composition. These variations are due probably to differences in both seasonal and soil conditions. Although there were no marked contrasts in growing conditions, season appears to influence composition more than soil. It is possible that in those areas where the growing conditions vary more widely from year to year, greater variations in composition would be found. Quality in grain is generally associated with good yields so yield data were compared with analyses. No consistent relationship between yield and quality was found for the varieties included in these studies. In a certain variety, high yield gave a lower analysis than low yields; in another variety, the reverse was true. These variations were obtained from such high-yielding spring oat varieties as Victory, Eclipse, and Three Grain, recommended varieties in this area.

TABLE 3.—*Percentage of total digestible nutrients in oats grown on different soil types and in different seasons.**

Variety	Amity, 1928†	Amity, 1929	Willamette, 1930	Chehalis, 1930
Joannette		80.29	80.67	
Abundance		78.79	76.98	
Madrid		77.71	78.01	76.48
Idamine		78.04	76.56	
Victory	77.11	78.22	77.69	76.79
Favell		78.63	77.70	77.21
Eclipse		77.37	77.37	
Senator		79.14	77.52	
La Connor		78.56	77.63	
Three Grain	76.19		76.23	75.62
Markton	79.19		80.31	
Gray Winter	80.84			82.80‡

*Computed according to Henry and Morrison on a moisture-free basis.
†Analyses made by California Experiment Station.
‡Grown in 1929.

The analyses of barley presented in Table 4 show the same lack of variation as was shown in Table 2. Three different analyses are shown for Hannchen, Peruvian, Trebi, and Ben Beardless. None of these varied more than 0.7% in the three analyses. In comparing the variation between the Willamette and Chehalis soil types in 1930, a very close agreement in total digestible nutrient value is found.

Hannchen, because of its plump kernel and high test weight, is considered by many feeders to be the best feeding barley available. Although the analyses of Hannchen show a high total digestible nutrient value, it is only slightly superior to the other varieties analyzed.

Another comparison of the effect of soil and season on the composition of oats and barley is made in Table 5. This comparison gives the average composition of nine varieties each of spring oats and winter barley and of four varieties of spring barley on different soil types and in different seasons. Unfortunately, it is not possible to distinguish between the effect of soil type and of season.

TABLE 4.—*Percentage of total digestible nutrients in barley grown on different soil types and in different seasons.**

Variety	Amity, 1929	Willamette, 1930	Chehalis, 1929	Chehalis, 1930
		Fall Planted		
Tenn. Winter		87.59	87.94	
Tenn. Winter Sel.		87.55	87.92	
Orel		87.69	87.80	
Alaska		87.42	87 64	
Pidor		87.47	88.04	
O. A. C. No. 7		87.49	87.60	87.30
O. A. C. Sel 6		87.92	87.24	
O. A. C. Sel. 1		87.74	87.19	
Wisconsin Winter		87.13	87.44	
		Spring Planted		
Hannchen	88.58	88.66		87.92
Peruvian	87.30	87.53		87.06
O. A. C. No. 7		88.03		87.55
Trebi	87.95	87.77		87.57
Ben Beardless	87.06	86.78		86.78

*Computed on moisture-free basis.

As indicated in previous tables, there is little variation in the total digestible nutrients, but there are some differences in protein content. This factor has not been emphasized thus far in these studies because of the difficulty in making the many comparisons.

TABLE 5.—*Effect of soil and season on the composition of oats and barley.*

Soil type and year	Crude protein %	Ether extract %	Ash %	Crude fiber %	T.D.N.* %
		Average of Nine Varieties of Spring Oats			
Amity, 1929	10.65	5.50	3.39	12.41	78.53
Willamette, 1930	9.11	5.33	3.81	13.05	77.79
		Average of Nine Varieties of Winter Barley			
Chehalis, 1929	9.09	2.16	2.84	6.29	87.64
Willamette, 1930	9.68	2.14	3.72	6.32	87.44
		Average of Four Varieties of Spring Barley			
Amity, 1929	9.83	2.20	2.66	6.26	87.72
Willamette, 1930	8 27	2.06	2.82	6.07	87.68
Chehalis, 1930	8.65	1.87	3.03	6.20	87.44

*Total digestible nutrients.

The value of the protein content is recognized, and of course must be given consideration in computing rations. Other things being equal, oats and barley of high protein content have the greatest value. The protein content of the groups of varieties reported in Table 5 shows more variation than the total digestible nutrients.

The highest protein content of oats and barley was obtained on Amity soil in 1929. This is probably due to season as this soil type

is lower in fertility and general productiveness than the other two soil types. There was less variation in the other factors than in protein content. The total digestible nutrient value is determined only upon complete analysis. If this value is related definitely to some individual factor, it would be of advantage to determine this relationship. Accordingly, correlations were computed between the total digestible nutrients and test weight, crude fiber, and ether extract. The results of these correlations are given in Table 6.

TABLE 6.—*Correlations of various factors with total digestible nutrients.*

Factor considered	Oats	Barley
Test weight	.487±.024	.579±.067
Crude fiber	.892±.020	.564±.071
Fat	.949±.089	
Fat	T.D.N.* other than fat .748±.059	

*Total digestible nutrients.

The correlation coefficients for oats show that the total digestible nutrients are closely related to both ether extract and crude fiber, but that the relationship with test weight is not so marked. Inasmuch as both ether extract and fiber are considered in determining the total digestible nutrients, it is to be expected that the correlation between these factors should be high. To this extent the use of these figures is open to criticism. The correlations do emphasize, however, that a total digestible nutrient value is closely associated with a high fat and a low fiber content. The correlation of .747± .059 between ether extract and total digestible nutrients other than fat does show that the percentage of fat is a fairly good indication of feeding value.

The data on test weight of oats are not conclusive in that no samples of low test weight were included. The test weight ranged from 35.5 to 42.5 pounds per bushel. Had samples of lower test weight been included, this relationship might possibly be changed.

No correlation is given between total digestible nutrients and fat in barley because of the low range in the fat content. In fact the small range in the total digestible nutrient of barley renders the correlations for test weight and crude fiber of questionable value. This illustrates the difficulty in using any one factor in barley to indicate the feeding value as shown by the total digestible nutrient.

RELATION OF FEEDING VALUE TO GRADES

The analyses of oats and barley present an entirely different picture than that given by the grades. Of the 46 samples of oats, all were graded No. 1 Gray, Red, White, or Black oats, although there was a marked variation in the nutrient value. Of the 45 barley samples, 24 were graded No. 1, 10 were graded No. 2, 7 were graded No. 3, and 2 were graded No. 4. Both samples grading No. 4 and five of the seven samples grading No. 3 were graded down because of low test weight. It should be pointed out that the low test weight was due for the most part to the adherence of awns to the grain rather than to shrunken

or shrivelled kernels. Nine of the ten No. 2 samples were of this grade because of an excess of skinned and broken kernels. One sample of barley graded No. 3 because of heavy stain. All of this variation in grade is in contrast to the small range in total digestible nutrients, as shown in Table 2. This lack of agreement between the two methods of indicating quality can be summarized differently. The oat samples, which show a range in total digestible nutrients of more than 7%, do not vary in grade. On the other hand, the barley samples, which show a variation in total digestible nutrients of only 2%, show a variation in grade of four numerical grades In one case the difference in quality is not indicated by the grades, while in the other, a difference which does not exist is indicated.

The present federal standards for oats are not always applicable to Oregon. Two of the most important grading factors, test weight and general appearance, seldom apply, as the Oregon oats usually weigh more than 32 pounds per bushel and are almost always bright. The grain exchanges recognize this by quoting prices on the basis of No. 2, 38-lb. oats, and so use test weight as a price factor with appropriate premiums and discounts for variation in test weight. Separate prices are quoted for gray and white oats Barley prices are also quoted on the basis of a minimum test weight. Premiums are paid for the high test weight Hannchen variety because of the preference of feeders for this type of barley, although analyses presented here do not show it to be significantly higher in feeding value than other varieties. The trade practices with oats correct in part the discrepancy pointed out between the total digestible nutrient value and the actual grade by using test weight as a factor in price quoting and by separating the Gray and White classes in price quotations. The condition is much less satisfactory for barley.

Attention has been called to the lack of agreement between the grades and the total digestible nutrients as indicators of quality. It should not be concluded, however, that the grades do not indicate feed value. Grading factors other than those considered in the samples included in these studies, such as foreign material and heat damage, are closely related to the feed value of oats and barley and should receive the attention of every buyer of feed grain. Furthermore, it should not be concluded that the factor of test weight never represents feed value. Some correlation between test weight and total digestible nutrient has been shown. The winter oats, which had high test weights, all had a high total digestible nutrient value in comparison to spring oats. It has been pointed out that the low test weight of barley was due to the adherence of awns rather than to shrunken and shrivelled kernels. All kernels were well developed and all samples had relatively the same total digestible nutrient value. While no data are presented to show a lower feeding value of oats and barley having a lower test weight because of adverse growth conditions, observations would indicate this to be the case. Pinched and undeveloped kernels are low in test weight and undoubtedly have less feeding value than plump kernels.

The feeder who is interested in buying oats and barley should have information as to the quality of the available supply. The most

important factors from his standpoint are the protein content and the total digestible nutrient value. The feeder who is growing his own feed is interested in the productiveness of a variety as well as in the composition. The grower producing oats and barley for sale is mainly concerned with yield and is not interested in composition except as it affects price. Agronomists should be in a position to give information on composition as well as on yield. Chemical characteristics of the varieties and the groups of varieties grown in given areas should be known and considered in making varietal recommendations. As new varieties of wheat are developed and tested in field trials, much attention is also given to chemical composition and to milling and baking behavior. The chemical composition of oats and barley is no less important or no less variable than wheat. Recommended varieties, therefore, should combine the qualities of high yield and desirable composition.

SUMMARY AND CONCLUSIONS

Complete analyses of 45 barley varieties and 46 oat varieties are given. These varieties were selected from the varietal plats at the Oregon Experiment Station. The samples were grown in two different years and on three different soil types.

The analyses presented show the percentages of crude protein, ether extract, ash, and crude fiber, expressed on the basis of a moisture-free sample. The percentage of total digestible nutrients, computed according to the method of Henry and Morrison, is used to compare varieties.

The barley samples show a lower protein content than the standard analyses of Henry and Morrison, but the percentage of total digestible nutrients and of other factors is similar. The range in the total digestible nutrient value of the 45 samples is only 2.4%. The Hannchen variety had the highest feeding value, but it was not significantly higher than the other varieties. No consistent difference between winter and spring types of barley was shown.

The protein content of oats was also lower than is shown by standard analyses, although the total digestible nutrient value is similar. A range of 7% was found in the total digestible nutrient value of the 46 samples of oats. The winter oat varieties were superior to spring varieties in that they had more protein, more fat, less fiber, and a higher total digestible nutrient value. The preference of feeders for the winter type of oats is amply borne out by these analyses.

Correlations between total digestible nutrients and ether extract, crude fiber, and test weight are given. The correlations with ether extract and crude fiber are higher for oats than for barley. The correlations for total digestible nutrient and test weight are low for both oats and barley.

All of the oat samples graded No. 1, although the range in total digestible nutrients shows significant differences in feeding value. In contrast, the grades of barley samples ranged from No. 1 to No. 4 with only a slight range in total digestible nutrient value. The grades and analyses of these samples show that feeding value is not always

reflected in the grade statement. Certain grading factors in the federal standards must be evaluated carefully or the grade statement will give an erroneous indication of quality.

Federal standards should be so changed that such discrepancies are lessened. Feed grades for barley, in which more accurate evaluation of certain factors is possible, should be developed. The adherence of awns, which has been pointed out as lowering both the test weight and grade of barley, is a desirable quality in rolled barley, while skinned and broken barley may be objectionable for rolling. On the other hand, there is a question as to the deleterious effects of skinned and broken kernels in feed barley to be fed whole or ground. Stain in barley and oats need not necessarily lower the feeding value.

Consideration should be given to the test weight of oats, either by eliminating it as a grading factor altogether and requiring a notation on the grade certificate or by providing premium grades for high test weight oats.

The value of feed grain is related directly to its protein content, which is variable. Optional supervised protein testing of feed grains might be worth while.

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SOME PHYSIOLOGICAL FACTORS INFLUENCING THE PRODUCTION OF FLAX FIBER CELLS[1]

B. B. Robinson[2]

The early investigations upon fiber flax were, in the main, an attempt to obtain data on the influence of various fertility factors on yields of straw, seed, and fiber. These studies, conducted under different conditions, resulted in conflicting interpretations. In the past decade investigations have continued in this field, but the investigators have tried to study it more from an anatomical viewpoint to determine just what occurs within the plants when they are grown and supplied with different so-called nutrients.

Following the excellent work initiated by the Irish Linen Industry Research Association, studies were made of the morphological characteristics of the fiber cells when grown under different conditions. This has involved the sectioning of many flax stems, the enlarging of these sections with the aid of a projection microscope, and measuring the cross-sectional area of the fiber cells. Previous results have shown that the percentage of fiber, as determined by the cross-sectional area of fiber cells in relation to the stem area, varies barely 3% for plants of different varieties, and for the average of mature plants grown under different conditions. However, a slight increase in the area of fiber cells combined with an increased area of stem and height would result in a much greater fiber yield per plant.

The work more recently reported has been in connection with plant breeding selection studies, and a few results have been reported from field fertilizer plats under conditions where it has been impossible to control many factors which influence the development of the fiber cells within a plant. No results have been reported from replicated field plat treatments or plants grown in greenhouses where some controlled conditions were possible. Further, no experimental results based upon cross-sections have been reported where two or more fertilizer elements were applied in combinations.

This paper presents and discusses results from water cultures grown under greenhouse conditions and from plants grown under field conditions in replicated plats.

PREVIOUS WORK

Davin and Searle (3)[3] and Davin (2) have reported practically the only determinations of the areas of fiber cells from cross-sections of stems. They concluded that the percentage of fiber of the flax plant

[1]Contribution from the Division of Fiber Plants, U. S. Dept. of Agriculture, in cooperation with the Oregon Agricultural Experiment Station, Corvallis, Ore. Also part of a thesis submitted to the Michigan State College in partial fulfillment of the requirement for the degree of doctor of philosophy. Journal article No. 104 (n.s.) of the Michigan Agricultural Experiment Station. Received for publication August 19, 1932.

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[3]Reference by number is to "Literature Cited", page 328.

is inherited, but failed to find any inherited external characters of the plant with which the percentage of fiber was correlated.

Renard (5) did not obtain convincing results in the one year in which he grew flax in soil with different moisture percentages. He found material differences in the inner structure of cross-sections of stems which were grown under similar conditions but did not obtain differences for area of fiber, wood, or pith cavity that were consistent for different races of flax or flax subjected to different moisture relations.

The cross-sections of flax stems studied by the different workers were usually taken in the middle of the stem at right angles to the length. Tammes (8) showed that the number of fiber cells, as well as the number of fiber bundles, varies throughout the length of the plant. However, the latter is fairly uniform, but the number of fiber cells is highest in the median portion of the stem.

Field fertilizer tests with fiber flax have been in some ways conflicting, due probably in many cases to soil heterogeneity. The work has been conducted mainly in Germany and Russia and was reviewed by Robinson and Cook (6). The results showed usually that increased yields might be obtained with nitrogenous fertilizers, especially when applied in combination with other elements, but most authors emphasize the importance of possible harmful effects of too much nitrogen on the quality of the fiber. Phosphorus has been shown to increase the percentage of fiber in cross-section and potash is given credit for increasing fiber yields, especially in combination with nitrogen.

EXPERIMENTAL PROCEDURE

GREENHOUSE METHODS

Soil cultures.—A sand deficient in available plant fertilizer elements was used as a culture medium. To this medium were added solutions of potassium and calcium nitrates made up with distilled water in such quantities as to allow the designation of low, medium, and high nitrogen content.

A specially prepared soil consisting of approximately one-fourth sand, one-fourth manure, and one-half muck, which was thoroughly mixed and screened, was used in another greenhouse experiment. These soil cultures containing flax plants were placed under different periods of illumination, including 10, 13 to 18, and 18 hours of light per day. The 13- to 18-hour illumination, as shown in Table 1, means that the plants when germinated received 13 hours of light per day. This period of illumination was increased 30 minutes each week until it reached 18 hours of light where it was kept constant.

Water cultures.—In 1931, plants were grown in a greenhouse in water cultures containing a few or all of the essential plant fertilizer elements in certain proportions, as shown in Table 2. In all cases where flax was grown in water cultures the plants were harvested at the age of 4 weeks. Only the living plants were measured and sectioned.

FIELD METHODS

The field experiments in 1931 were conducted upon a Hillsdale soil. There were 14 different fertilizer treatments applied to these field plats, and each treatment was replicated three times. The applications of fertilizer were at the rate of 400 pounds per acre. At the age of 41 days five seedling plants, representing as near as possible the average size from each plat, were selected, measured, and preserved in a formalin-acetic-alcohol fixing solution for later sectioning. At that time there was no disease present in any of the plats, but a few weeks later wilt (*Fusarium lini*) appeared in the field and greatly affected the total yields from several plats. The wilt was not found to be correlated with any fertilizer treatment. Five mature plants, age 92 days, which were not noticeably affected by the fungous disease were selected from each plat, measured, and preserved in a manner similar to that used for the seedling plants. The data were obtained from 280 seedling and 280 mature plants; that is, 20 plants were sectioned from each of the 14 treatments in the seedling stage and 20 from each of the 14 treatments in the mature stage.

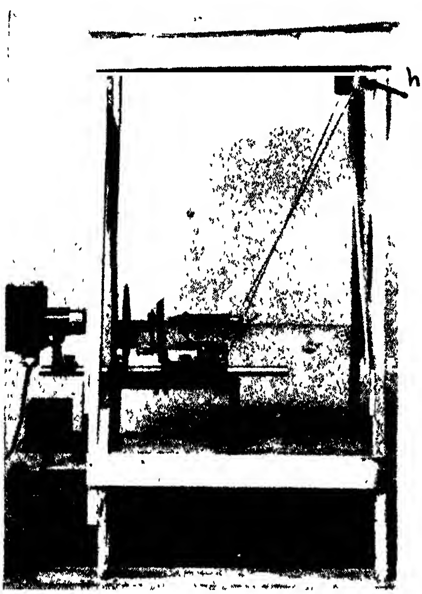

FIG. 1.—Side view of projection microscope and table used for enlargement of flax plant cross-sections. The fine adjustment of the microscope was operated by a handle (*h*) at the right hand upper corner of the table.

HISTOLOGICAL METHODS

All of the plants for sectioning were killed and fixed in the formalin-acetic-alcohol solution, desilicated for 3 days in a 10% solution of hydrofluoric acid, imbedded in celloidin, and finally cut approximately 40 microns thick on a sliding microtome. This procedure was similar to that used by Searle (7) but different in technic.

The sections after staining with methyl green were enlarged with a projection microscope shown in Fig. 1. The images were thrown on tracing cloth stretched over a glass table top and were focused by means of a handle (*h*) shown in Fig. 1. The number of fiber cells per cross-section was counted, and the area of stem and area of fiber were measured with the planimeter. Due to the fact that many sections were torn slightly in cutting, it was necessary to have some means of calculating the fiber area of a section where it was impossible to measure the complete 360 degrees. This was possible by having the table top movable, as shown in Fig. 2; and with a slight shift of the

table top from one side to the other the image could be centered within a protractor and definite angles measured. All measurements were taken in duplicate, and at least two different measurements were taken from each stem.

In the mature stems the fiber bundles were always distinct and the fiber cells could be distinctly classified as either fiber cells or paren-

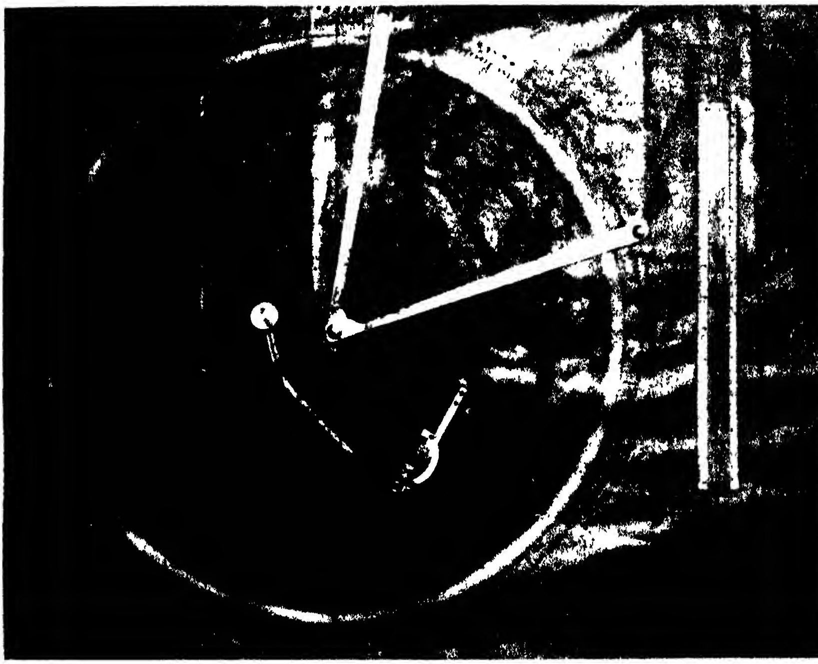

FIG. 2.—Top view of the moveable table top, showing the protractor and planimeter used in measuring the fiber cells and stem areas.
The dark circular area inside the outer drawn protractor circle indicates the size of the hole in the table top which was covered with plate glass and tracing cloth through which the images were projected.

chyma cells. In the seedling sections the thickening of the fiber cell walls had not proceeded very far, and there were many cells which were probably in a very early transitional stage, which made classification difficult. In Fig. 3 it may be noted that in the seedling section the fiber cells are surrounded by parenchyma tissue, while in the mature stems this tissue has almost disappeared and the fiber cells have greatly increased in number.

THE ORIGIN OF FLAX FIBER CELLS

Strands of flax fiber cells are usually called bast fibers. This term is now understood to include all fibers outside the cambium layer, including phloem, pericycle, and cortex fibers. The origin of the flax fiber cells has been somewhat disputed. Herzog (4, page 119) mentions earlier studies in which Tammes (8) attributes the fiber cells to primary cambium origin as sclerenchyma fibers of the pericycle,

neither belonging to the cortex nor to the bast. Winter (9) disputes this. However, it seems as though the difference of opinion may be entirely due to differences in terminology. In several of the seedling sections studied by the writer, the fiber cells showed plainly as pericycle fibers. In these sections the endodermis layer (Fig. 3) appears distinctly as it would in root sections and definitely shows the fiber

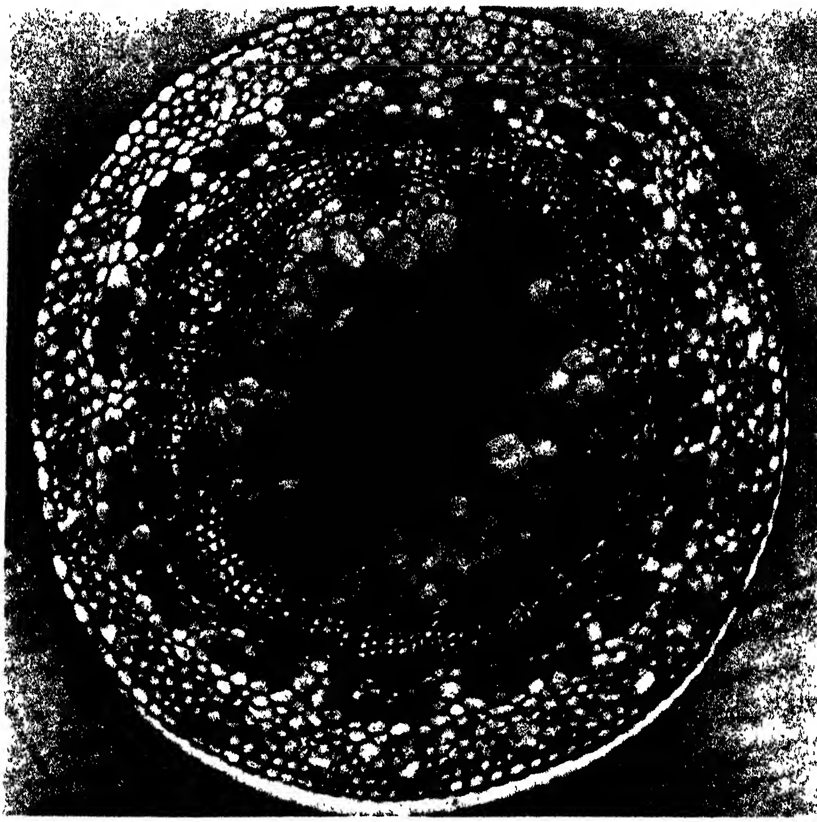

FIG. 3.—Photo-micrograph of a seedling flax stem, showing a fairly distinct endodermis (E).
Inside the endodermis may be distinguished the fiber cells, showing them to arise from the pericycle.

cells to be pericycle fibers. Figs. 4 and 5 are photo-micrographs of portions of cross-sections from flax stems and illustrate the variability in size, number, and area of the fiber cells within different plants.

EXPERIMENTAL RESULTS

INFLUENCE OF DIFFERENT PERIODS OF LIGHT DURATION ON HEIGHT OF FLAX PLANTS

Flax plants grown under different periods of light in 1928 responded very differently, as shown in Table 1. Adams (1) grew flax plants exposed to different periods of light. The plants were measured at the

TABLE 1.—*Results obtained from flax plants grown in triplicate soil cultures in a greenhouse in 1928 and measurements obtained from sectioning one plant from each treatment.*

Treatment	Data from single plant sectioned						Data from plants not sectioned		
	Fiber %	No. of fiber cells	Area fiber. sq cm.	Area stem, sq. cm.	Length stem cut. cm.	Yield of fiber, cu. mm.	Average length, cm.	Stem weight, gram	Fiber* %
				Nitrate Solution					
None	5.94	203	33.9	570.0	64	28.65	57.3	0.058	23.65
Low	8.11	255	47.9	590.7	67	37.42	52.7	0.061	21.20
Medium	7.28	252	35.2	483.1	57	30.52	58.7	0.070	21.55
High	6.63	271	36.2	543.3	63	27.81	51.5	0.083	19.27
				Photoperiodism					
10 hours	6.22	405	101.5	1633.1	66	125.55	83.7	0.153	22.11
13–18 hours	7.03	386	73.7	1065.1	94	85 24	78.2	0.126	22.03
18 hours	4.03	211	20.9	348.0	33	14.41	46.5	0.059	24.27

*Percentage fiber determined by retting and scutching.

age of 30 and 47 days for two series and taller plants were produced under the longer periods of illumination. As Adams gave no additional data for older plants, it is impossible to tell if those with shorter light exposure did not finally grow taller than those having a longer exposure to light. The plants reported in Table 1 which were grown

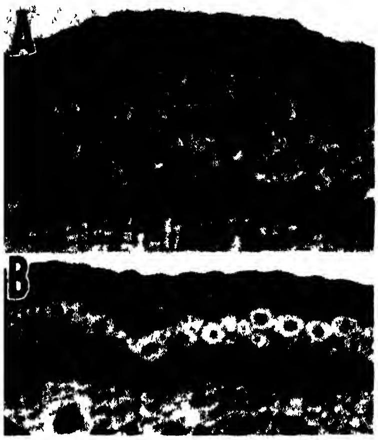

FIG. 4.—Photo-micrographs of portions of cross-sections from flax stems of equal area and magnification showing in A a high percentage of fiber, 10.65; and in B a low percentage of fiber, 6.87.

FIG. 5.—Photo-micrographs of portions of cross-sections from flax stems of equal area and magnification, showing in A a high number of small fiber cells, 650; and in B a low number of large fiber cells, 339.

in an 18-hour light period per day grew the most rapidly as seedlings, but flowered and matured in 75 days without attaining any considerable height. Those grown in a 10-hour light period per day grew very slowly at the beginning, but eventually attained the greatest height and after 110 days started to flower, at which time the experiment was discontinued. The plants grown in a 13- to 18-hour light period grew at an intermediate rate and attained an intermediate height. Fig. 6 shows plants 75 days old, grown under different periods of light.

INFLUENCE OF DIFFERENT PERIODS OF LIGHT DURATION ON FIBER YIELD OF FLAX PLANTS

The flax plants grown under different periods of light duration gave very large differences in fiber yields, which is perhaps best shown by figures obtained by multiplying the cross-sectional area of fiber by the height of the plant. The plants grown in an 18-hour light period per day matured so quickly that they did not attain normal size and produced a small number and a very small area of fiber cells and a low yield of fiber in cubic millimeters. The short-day plants yielded eight times as much fiber in cubic millimeters per plant as the long-day plants. The plants which germinated in 13 hours of light per day and received additional light as they grew until at maturity they were receiving 18 hours of light per day developed normally. They had a high percentage of fiber, a good number of fiber cells, and were plants of good volume.

INFLUENCE OF NUTRIENT CONDITIONS ON HEIGHT OF FLAX PLANTS

The tallest flax plants produce the greatest yields of fiber. Results are shown in Table 1 with plants grown in a greenhouse in 1928 in soil cultures to which different amounts of nitrate solution were added. Apparently the nitrate alone had little effect in increasing the height or cross-sectional area of the plants in this experiment.

In the water culture experiments the length of stem was the greatest where three-salt cultures, particularly the N2PK culture in the first series, Table 3, were used instead of one-salt cultures. In the second series of plants grown in water cultures in 1931 in the greenhouse, jars 3 and 4, Table 2, gave the greatest dry weights and height of plants. In the third series of plants grown in the greenhouse the same year in media containing different nutrient salts, jars 5 and 9, Table 2, produced the highest yields of dry weights of tops and roots and the tallest plants. It is interesting that the cultures which yielded the best in the first and second series of water cultures were cultures with very similar analyses, being high in phosphorus and medium high in potassium. Two of the best-yielding cultures (jars 4 and 5) of the third series resembled in their analyses those which yielded well in other experiments.

FIG. 6.—Flax plants of the same age, 75 days, grown in 1928 under different periods of light.
Treatments were as follows: A, 10 hours of light per day; B, 13–18 hours of light per day; and C, 18 hours of light per day. The plants in C have mature seed; those in B are in bloom; while those in A are very far behind in their development.

In Table 5 are shown the actual stem lengths of seedling and mature plants from replicated field fertility plats. A study of the seedling stem length shows that nearly all of the fertilizer treatments produced taller plants than the no-fertilizer treatment. The treatments containing nitrogen, particularly in combination with other elements, produced the tallest plants. However, the lengths of stems of the mature plants from different fertilizer treatments varied only from 66.0 to 75.8 cm. In only a few cases are the differences statistically significant. The relationship in height between the different fertilizer treatments in the mature stems is similar to that of the seedling

TABLE 2.—*Results obtained with water cultures of flax grown in 1931, together with the number of cc of salt solution (1/M) added to each 12-liter jar; solutions changed at the end of 2 weeks and the cultures grown only 4 weeks; J. W. S. flax was grown in all jars.*

Jar No.	Formula	$Ca(NO_3)_2$, cc	NaH_2PO_4, cc	KCl, cc	$MgSO_4$, cc	Average height, cm	No. plants Alive	No. plants Dead	Weight roots, grams	Weight stems, grams
					First Series*					
1	N	62.4	—	—	180	6.76	29	0	0.230	0.450
2	P	—	216	—	180	6.03	30	2	0.330	0.280
3	K	—	—	216	180	5.66	28	1	0.270	0.260
4		—	—	—	—	6.32	30	0	0.295	0.280
5	PK	—	216	216	180	6.09	16	14	0.295	0.300
6	NPK	62.4	216	216	180	9.65	30	1	0.845	0.820
7	2NPK	124.8	216	216	180	11.83	18	11	0.715	0.780
8	NK	62.4	—	216	180	6.34	22	3	0.195	0.365
9		—	—	—	—	7.50	32	0	0.110	0.340
10	N2PK	62.4	432	216	180	17.13	26	0	0.970	1.530
11	NP	62.4	216	—	180	9.88	25	2	0.465	0.570
12	NP2K	62.4	216	432	180	6.40	10	20	0.355	0.600
					Second Series†					
1		30	400	400	180	10.12	26	2	0.235	0.690
2		60	400	300	180	16.26	33	0	0.400	1.690
3		90	400	200	180	21.64	37	0	0.670	3.250
4		120	400	100	180	25.09	37	0	0.940	4.965
5		120	300	200	180	19.25	39	0	0.590	2.695
6		120	200	300	180	13.77	27	5	0.190	1.145
7		120	100	400	180	9.56	34	3	0.200	1.010
8		60	300	400	180	11.33	32	3	0.220	1.070
9		90	200	400	180	8.98	33	1	0.160	0.775
10		90	200	300	180	13.71	38	1	0.320	1.580
11		75	250	350	180	9.92	16	15	0.140	0.790
12		105	250	250	180	17.48	33	0	0.445	2.270

Third Series‡

—	—	$Ca(NO_3)_2$, cc	KH_2PO_4, cc	$MgSO_4$, cc	Ratio	—	—	—	—	—
1		31.2	43.2	480	1-1-8	11.82	9	20	0.145	0.550
2		31.2	345.6	60	1-8-1	11.72	15	17	0.300	0.880
3		249.6	43.2	60	8-1-1	11.10	21	18	0.330	1.015
4		62.4	216.0	180	2-5-3	12.88	27	14	0.430	1.190
5		93.6	129.6	240	3-3-4	15.96	37	3	0.585	1.485
6		93.6	172.8	180	3-4-3	12.97	25	12	0.440	1.180
7		31.2	172.8	300	1-4-5	12.58	22	16	0.355	0.965
8		156.0	172.8	60	5-4-1	10.23	9	23	0.230	0.580
9		124.8	43.2	300	1-4-5	16.86	27	7	0.375	1.305
10		187.2	86.4	120	6-2-2	11.26	36	7	0.450	1.145
11		62.4	86.4	360	2-2-6	13.46	28	11	0.440	1.025
12		124.8	129.6	180	4-3-3	13.41	13	23	0.305	1.030

*Additional salts 10 cc iron tartrate, 0.2%, and 5 cc MnCl, 0.2%.
†20 cc iron citrate added.
‡Additional salts 20 cc iron citrate, 3 cc $MnSO_4$, M/14, and 3 cc $HgBO_3$, M/5.

TABLE 3.—*Results, with probable errors, obtained from sectioning 10 stems of each treatment from the first series of seedling water culture plants grown in water cultures in 1931.**

Treatment	Fiber %	No. of fiber cells per stem	Area fiber cells per stem sq. cm.	Area stem per stem, sq. cm.	Average height, mm.	Yield of fiber in cu. mm.
Tap water	4.72±.18	93.8±5.3	11.3±.7	244.6±14.9	65.2±1.1	1.108±.068
N	3.27±.24	94.6±4.7	12.0±.7	374.7±8.5	67.6±1.2	1.217±.080
P	4.35±.17	81.3±1.9	12.8±.5	296.5±8.3	60.3±1.1	1.146±.022
K	5.77±.18	87.5±3.0	13.3±.6	232.2±7.7	56.6±1.4	1.132±.029
N-P	3.80±.21	116.3±6.4	18.2±.9	481.1±13.3	98.8±1.8	2.668±.137
N-K	3.89±.37	96.9±8.3	14.1±1.4	363.7±12.2	63.4±1.5	1.331±.137
P-K	3.86±.26	94.9±5.3	12.0±.8	316.1±11.9	60.9±2.0	1.096±.081
N-P-K	3.80±.14	113.6±3.6	19.2±1.1	508.7±25.4	96.5±1.8	2.702±.162
2N-P-K	4.18±.16	115.2±3.8	23.1±.7	562.4±22.8	118.3±2.6	4.022±.148
N-2P-K	4.75±.26	150.4±3.1	35.0±2.3	735.7±21.1	171.3±4.6	8.908±.630
N-P-2K	3.08±.29	84.2±7.4	12.7±1.7	386.9±12.7	64.0±2.1	1.216±.165

*The area of fiber cells and stem area are magnified 67,600 fold.

stems, with the exception that the results of the 0–0–0 and 4–0–8[4] treatments are too high.

INFLUENCE OF NUTRIENT CONDITIONS ON PERCENTAGE OF FIBER OF FLAX PLANTS

Under field conditions average yields of fiber seldom exceed 400 pounds per acre. If this is considered as a yield from mature stems with 8.5% of fiber as measured by cross-sectional area, then an increase of 1% of fiber per stem would actually be an additional yield of 47 pounds of fiber, or 11.75% increase in total yield per acre. This would probably be the maximum obtainable, provided a fertilizer did not cause a greater height of plant, an increase in areas of stems, or an increase in the stand of plants per acre of ground. In the field experiments reported here, the greatest difference in percentage of fiber due to fertilizer treatment was $1.54 \pm .17$. In water cultures in the greenhouse experiments where conditions were such that greater variability could be secured, the potassium (K) culture yielded $5.77 \pm .18\%$ fiber and the NP2K treatment with an excess of potassium yielded only $3.08 \pm .29\%$ fiber.

Seedling flax plants grown under field conditions did not vary more than 1%, as between treatments, in percentages of fiber. A difference of approximately 0.5% fiber between any two treatments is statistically significant.

The percentage of fiber in the mature plants grown under field conditions was twice as great as it was in the seedling plants. This indicates that many cells surrounding the fiber cells at the stage of the plants when the seedlings were measured had not progressed far enough in their development to be called fiber cells, though later thickening of the cell walls took place. As in the seedling series, the mature stems did not show great differences in fiber percentages as between the different treatments and the data show significant differences only in one or two cases. For some reason not understood the check plat yielded next to the highest percentage of fiber and the results of the 0–16–0 fertilizer appear inconsistent.

INFLUENCE OF NUTRIENT CONDITIONS ON NUMBER OF FIBER CELLS OF FLAX PLANTS

The data on the production of fiber cells shown in Table 1 are based upon too few sections per treatment to have any great significance, but they serve in a way to indicate the trend and agree with some conclusions drawn from results obtained in other experiments.

The results with water cultures grown in 1931 show the necessity of having a complete solution (three salts) for the greatest production of fiber cells. One exception was a complete solution containing an excess of potassium (NP2K) which was too toxic for the plants, retarding their growth and in many cases killing them. It cannot be said from these experiments whether potassium or nitrogen had a

[4]The order of the fertilizer elements in analyses in this paper is nitrogen, phosphorus, and potassium.

greater influence on the production of fiber cells, but it is definitely shown that potassium in excess decreases their number.

The number of fiber cells per stem is fairly constant in seedling plants grown in field replicated fertility plats and it is similar to the percentages of fiber per stem. A difference of approximately 25 cells in Table 4 may be regarded as a significant difference, and nearly half of the treatments show an increase of 25 cells over the check plat. Fertilizers giving the greatest increase in number of cells per plant over the control are 4-8-8, 4-16-0, and 4-16-8. The mature plants obtained from the same field replicated fertility plats in 1931, the results of which are shown in Table 6, indicate that no one treatment effected a significant increase or decrease in the number of fiber cells when compared with the check. The two lighter applications of calcium carbonate resulted in the lowest number of fiber cells. Possibly an increased production of fiber cells depends on a definite ratio of the fertilizer ingredients or a proper balancing of the nutrient elements. In a few cases it appears that potassium did influence the production of fiber cells, but there were instances where just as large increases were secured from nitrogen or phosphorus.

INFLUENCE OF NUTRIENT CONDITIONS ON AREA OF FIBER CELLS OF FLAX PLANTS

The opinion of some flax breeders has been that there is a critical stage in the development of the flax fiber cells and that this is the very early seedling stage. The data presented here show that in field seedling plants even 41 days old the fiber cells are not far enough along in their development to distinguish more than one-third of them. The development and thickening of the fiber cell walls probably continue almost to the time of the plants' maturity. However, it is believed from results obtained that even though all the fiber cells in seedling plants cannot be distinguished, the number and area of the ones which can be distinguished are representative of the future fiber development when comparison is made between treatments.

A number of water culture treatments, shown in Table 3, receiving one or more salts have a significantly larger fiber area as compared with that of plants grown in tap water. These increases seem to be directly correlated with the increase in the area of stem and the number of fiber cells per stem. As the area of stem increases, the percentage of fiber as measured by cross-sectional area remains approximately the same, but an increase in the area of fiber is obtained.

Results obtained upon field-grown seedling plants and presented in Table 4 show that a difference of approximately 6.5 sq. cm. in area of fiber cells is significant. Many of the treatments show even larger differences. The greatest increase above the check plat was caused by the 4-16-8 treatment. This amounted to 53%. The areas of fiber cells in the mature stems are variable, but only one treatment, 4-0-8, appears to have caused a significant increase in area of fiber cells over the check plats. In both the seedling and mature plants the area of fiber cells is closely correlated with the area of stem. Therefore fertilizers tending to increase the area of stem would also increase the area of fiber cells.

TABLE 4.—*Data obtained from seedling stems which were*

Treatment	Percentage of fiber				
Series No.	1	2	3	4	Average
0-0-0 . . .	4.02± .10	4.37± .17	4.20± .23	3.70± .15	4.17± .08
4-0-0	3.92± .13	4.54± .32	6.60± .25	4.15± .24	4.80± .12
4-16-0	4.76± .21	4.50± .08	4.67± .05	4.91± .25	4.71± .08
4-16-8	4.87± .18	4.72± .07	5.53± .09	4.60± .17	4.93± .07
4-16-16	4.44± .20	4.48± .19	4.72± .23	3.91± .21	4.39± .10
0-0-8	4.86± .13	4.05± .24	4.59± .10	4.18± .21	4.42± .09
0-16-8	3.86± .26	4.36± .14	4.37± .21	4.01± .26	4.15± .11
8-16-8	4.78± .20	4.11± .18	4.08± .18	4.02± .20	4.25± .10
4-8-8	4.04± .16	4.68± .38	4.90± .32	4.54± .06	4.54± .13
4-0-8	3.85± .15	4.62± .22	5.13± .33	3.65± .21	4.31± .12
0-16-0	3.84± .19	lost	4.62± .15	3.71± .10	4.05± .09
$CaCO_3$†	3.97± .23	4.98± .21	4.65± .22	3.83± .06	4.36± .10
$CaCO_3$‡	4.35± .18	4.53± .23	5.00± .31	3.53± .18	4.35± .12
$CaCO_3$‖	3.63± .23	4.44± .31	4.08± .04	3.65± .10	3.95± .10
	Area of fiber cells, sq. cm.				
0-0-0	31.5±1.8	26.3± .6	45.6±4.1	40.5±1.6	36.0±1.2
4-0-0	34.3±3.0	34.7±3.1	76.2±7.0	42.4±3.1	46.9±2.2
4-16-0	46.0±1.1	32.3±1.5	53.8±2.3	63.4±4.5	48.9±1.3
4-16-8	41.7±2.1	49.5±2.6	71.4±3.8	57.6±4.1	55.1±1.6
4-16-16	49.5±3.9	39.4±3.2	58.9±2.7	53.2±3.0	50.3±1.6
0-0-8 .	29.7±1.9	27.9±1.1	48.9±2.5	46.5±3.1	38.2±1.1
0-16-8	33.6±2.4	42.6±1.8	36.9±1.6	39.8±2.4	38.2±1.0
8-16-8	43.4±3.3	45.1±3.8	65.4±3.7	65.0±6.2	54.7±2.2
4-8-8 . .	46.7±3.3	48.4±5.9	53.2±3.1	52.0±1.8	50.1±1.9
4-0-8	34.3±3.4	41.3±1.8	74.4±4.9	43.1±3.4	48.3±1.8
0-16-0 .	31.8± .8	lost	55.2±4.1	40.0±1.1	42.3±1.4
$CaCO_3$† .	41.7±2.2	43.5±2.7	38.1±1.5	45.9±1.8	42.3±1.0
$CaCO_3$‡	45.4±2.6	43.8±2.8	54.8±2.9	40.0± .8	46.0±1.2
$CaCO_3$‖	29.1±3.4	36.2±3.0	45.9±2.2	41.8±2.2	38.3±1.4

*Each result, with its probable error, is the average of five stems which were sectioned, in square centimeters magnified in area 67,600 fold.
†2,000 lbs. ‡4,000 lbs. ‖6,000 lbs.

INFLUENCE OF NUTRIENT CONDITIONS ON THE STEM AREA OF FLAX PLANTS

The positive correlation between cross-sectional area of the flax stem and area of fiber cells has been mentioned. In general, then, greater yields of fiber may be expected with such fertilizer application as effect an increase in area of the stem. The results of water culture experiments (Table 3) show that the area of the stem was the greatest with the complete solutions (three salts) and less for the one- and two-salt culture treatments. The area of the stem for seedling field plants increased with the application of fertilizer, and the 8-16-8 application gave a 45% increase over the check plat but resulted in a slight reduction in area of stem, as compared with the check in the mature plants.

INFLUENCE OF NUTRIENT CONDITIONS ON YIELD OF FIBER IN CU. MM. OF FLAX PLANTS

Naturally the large differences in percentage of fiber, area of fiber cells, and height of plants between the different water cultures shown

*grown in the field in 1931 in four different fertilizer series.**

Number of fiber cells				
1	2	3	4	Average
186.8± 5.8	182.0± 6.7	217.2± 6.6	183.6±10.2	192.4± 3.8
210.6± 9.4	176.4± 7.2	225.0±13.2	208.6± 9.6	205.2± 5.0
221.2± 5.2	228.0± 6.6	240.8± 7.1	247.8± 9.2	234.5± 3.6
223.2±11.1	215.4± 8.5	241.2±12.5	248.4±12.8	232.1± 5.7
234.4± 9.5	231.6± 5.9	230.4± 8.5	226.8±13.2	230.8± 4.8
199.4± 8.9	160.0± 8.1	223.0± 9.1	228.8±11.9	202.8± 4.8
182.8± 9.5	219.2± 7.1	186.6± 7.7	217.2±12.7	201.5± 4.8
222.6±11.7	230.4±12.2	221.8±10.3	211.2± 8.8	221.5± 5.4
230.6± 4.6	247.6±19.2	249.4± 7.2	258.8± 9.9	246.6± 5.8
183.4± 8.6	206.2± 5.3	220.6±18.2	202.6±14.4	203.2± 6.3
198.2±10.1	lost	247.8± 8.2	219.8± 8.3	221.9± 5.1
188.4± 6.3	220.0± 5.6	191.8±13.7	231.6± 4.5	208.0± 4.2
214.2±15.7	204.8± 8.9	216.6±10.3	253.4± 6.9	222.3± 5.5
176.8± 9.2	171.0± 5.8	221.2±12.2	191.0±16.1	190.0± 5.7
Area of stem, sq. cm.				
789.1±51.3	609.6±26.4	1,071.8±46.4	1,125.6±66.2	899.0±24.8
868.2±59.8	766.9±47.0	1,135.5±63.1	1,036.2±64.1	951.7±29.5
989.9±69.6	721.7±36.5	1,148.5±44.3	1,297.4±81.1	1,039.4±30.3
868.9±51.0	1,050.9±61.9	1,291.9±72.0	1,252.5±67.7	1,116.1±31.8
1,111.7±60.8	875.9±48.9	1,281.7±88.6	1,375.7±65.1	1,161.3±33.7
607.7±27.6	703.0±41.9	1,059.2±34.2	1,120.3±54.7	872.6±20.4
870.5±25.8	995.8±63.8	853.3±37.6	1,004.9±48.9	931.1±23.1
897.7±37.3	1,089.8±68.8	1,631.8±29.8	1,591.9±75.4	1,302.8±42.3
1,160.5±70.8	999.9±70.7	1,113.6±64.8	1,148.7±47.4	1,105.7±32.1
880.6±72.4	911.4±53.9	1,458.5±52.7	1,173.9±50.4	1,106.1±29.0
850.2±48.1	lost	1,196.2±79.6	1,087.6±46.5	1,044.7±34.7
1,066.2±53.5	887.4±65.8	831.2±44.3	1,195.1±32.0	994.9±25.2
1,055.0±69.1	967.1±47.2	1,103.4±31.6	1,150.3±39.1	1,069.0±24.4
806.4±90.3	814.7±22.6	1,127.4±54.7	1,144.8±53.7	973.3±30.2

or an average of 20 stems per treatment. The area of fiber and area of stem are

in Table 3 produced large differences in the yield of fiber expressed in terms of cu. mm. per plant. The N2PK culture yielded approximately 8 times as much fiber as the one- and two-salt cultures and 2.25 times that of the 2NPK culture. The N2PK culture is low in nitrogen but high in phosphorus and potassium. The large increase in the yield of fiber in cu. mm. obtained from several of the water cultures is due largely to the influence of the fertilizer salts on the average height of the plants.

In Table 5 a difference of 4 cu. mm. is significant for most yields of fiber for the seedling field-grown plants. This increase was obtained in all of the complete fertilizer plats when compared with the check treatment. The greatest increases were obtained with the 0–16–8, 8–16–8, 4–16–8, and the 4–16–16 treatments, and were partly accounted for by the fact that the fertilizers produced taller plants.

The variability in the yield of fiber expressed as cu. mm. per mature stem for different treatments, as shown in Table 5, is not due so much to the variability in the length of stems as to the area of fiber cells (Table 6). The average probable error for yield of fiber in cu. mm.

for these mature stems is 4.4, so significant differences between treatments were obtained in only a few cases. Additional data will have to be obtained to understand this problem clearly.

TABLE 5.—*Data on stem lengths and yield of fiber in flax plants grown under field conditions in 1931.*

Treatment	Seedling stem lengths in cm.					Yield of fiber, cu. mm.
Series No.	1	2	3	4	Ave.	
0-0-0	20.1± .7	23.6± .6	29.6±1.0	22.5± .6	24.0± .4	12.8± .5
4-0-0	23.6±1.1	23.9± .5	28.4± .4	26.0± .7	25.5± .4	17.7± .9
4-16-0	27.1± .9	19.9± .6	29.0± .4	37.5±1.8	28.4± .5	20.5± .6
4-16-8	25.4± .8	22.5± .4	34.2±2.1	30.4± .7	28.1± .6	22.9± .8
4-16-16	24.8± .6	25.5±1.0	33.1± .5	38.4±1.4	30.5± .5	22.7± .8
0-0-8	18.4± .1	17.2± .4	25.9± .5	34.0±1.0	23.9± .3	13.5± .4
0-16-8	18.5± .4	23.0±1.3	26.2± .4	29.3± .9	24.3± .9	24.3± .4
8-16-8	23.2± .7	25.0±4.5	36.0±1.6	33.4±1.2	29.4±1.2	23.8±1.4
4-8-8	26.9± .9	26.5±1.2	30.1±1.4	34.0±1.1	29.4± .6	21.8± .9
4-0-8	21.1± .8	17.6± .6	32.3±1.5	27.9±1.4	24.7± .6	17.6± .8
0-16-0	21.9±1.2	17.9± .5	33.7±1.3	31.8±1.3	26.3± .6	16.5± .7
$CaCO_3$*	23.3± .3	23.0±1.0	22.4± .8	29.8± .8	24.6± .4	15.4± .4
$CaCO_3$†	23.4± .9	21.3± .6	29.1±1.3	29.1± .4	25.7± .4	17.5± .5
$CaCO_3$‡	19.4± .7	21.6±1.3	28.0± .5	23.2±1.5	23.1± .5	13.1± .6
	Mature stem lengths in cm.					
0-0-0	67.6±1.5	71.4±1.0	74.2± .3	75.8± .5	72.3± .5	149.3±4.0
4-0-0	67.6±1.1	61.4± .9	68.6±1.0	66.3±2.8	66.0± .8	120.8±2.8
4-16-0	71.9±2.9	68.1±2.8	75.4±2.7	71.8±1.9	71.8±1.3	123.6±3.8
4-16-8	79.6±1.8	74.8±2.1	74.9±1.1	70.2±1.4	74.9± .8	134.4±4.3
4-16-16	69.6±2.0	73.0±2.7	73.7±1.3	70.7±1.7	71.8±1.0	140.3±4.2
0-0-8	70.1±2.7	66.7±1.6	76.5±1.7	76.9±1.5	72.5±1.0	148.8±4.9
0-16-8	62.5±1.5	69.7±1.7	77.4±2.8	67.2±1.3	69.2±1.0	124.4±3.8
8-16-8	70.8±2.2	63.1±1.9	76.9±1.8	77.0±2.9	72.0±1.1	134.3±4.1
4-8-8	66.3±2.2	78.2±1.7	65.8± .9	77.2±5.9	71.9±1.6	129.8±5.3
4-0-8	74.2±2.6	72.4±2.1	75.6±1.8	81.2±1.2	75.8±1.0	180.4±7.2
0-16-0	74.7±1.1	69.2±2.8	78.6±1.0	75.3±1.6	74.5± .9	136.6±4.5
$CaCO_3$*	60.6± .9	74.3±2.2	67.7±1.2	71.1±2.6	68.4± .9	119.4±4.5
$CaCO_3$†	68.4±1.5	72.4±1.0	69.5±1.6	72.4±1.7	70.7± .7	118.4±3.5
$CaCO_3$‡	69.6±1.5	65.9±2.0	73.9±1.6	75.8±2.7	71.3±1.0	151.9±4.5

*2,000 lbs. †4,000 lbs. ‡6,000 lbs.

A FERTILIZER ANALYSIS FOR FLAX PLANTS

Results on seedling plants grown in water cultures and in the field are comparable, but the results on mature stems grown in the field are inconclusive. Application of some nitrogen seemed necessary for the best results with the seedling field-grown plants. The data from the field-grown mature plants were inconclusive. Water cultures very high in phosphorus and medium high in potassium gave the best results. Potassium when applied as a single salt in water cultures gave the highest percentage of fiber in the series in which it was tested. In the field experiments the best results were usually obtained with an 8% potassium treatment, while a 16% treatment seemed to be too concentrated. This was also the case in the water cultures where the NP_2K solution was so toxic that it killed some of

the plants and resulted in a low percentage of fiber in those that survived. From all of these results it seems probable that an analysis similar to a 4–16–8 is the most desirable for fiber flax under conditions where little is known regarding the soil requirements. Possibly the phosphorus percentage might be increased for better results, but this will have to be tried out under field conditions.

SUMMARY

Photo-micrographs from seedling flax stems prove that the flax fiber cells arise from the pericycle.

Flax plants eventually attain the greatest height in short periods (10 hours) of light per day but elongate and mature the quickest in long periods (18 hours) of light per day. The short-day plants yielded 8 times as much fiber as the long-day plants.

The height of a flax plant more than anything else determines how much fiber it contains. A complete nutrient solution was necessary in water cultures to produce the tallest seedlings. Nitrogen, particularly in combination with other elements, produced the longest stems in field-grown seedling plants, but results from these same fertility plats showed that plants fertilized with phosphorus and potassium equalled or surpassed the nitrogen plats at maturity. Combinations of potassium and nitrogen seem to be desirable for best results.

Seedling field-grown plants gave the highest percentages of fiber with the following treatments: 4–0–0, 4–16–0, and 4–16–8. The percentage of fiber in the mature field-grown plants was twice as great as it was in the seedling plants. Some of the results substantiate the conclusions of other workers that phosphorus increases the fiber percentage and that nitrogen decreases it, but there were exceptions to this rule

The number of fiber cells increases after seedling plants are 6 weeks old. The number of fiber cells in field-grown seedling plants increased with additions of fertilizers, but no significant increase or decrease was obtained in mature stems for any fertilizer treatment when compared with the check.

The area of fiber cells as seen in cross-section is closely correlated with the area of stem, and fertilizers tending to increase the area of stem and probably the number of fiber cells will increase the area of fiber cells.

Water cultures which produced the best yields of fiber were high in phosphorus and medium high in potassium. The 0–16–8, 4–16–8, 8–16–8, and 4–16–16 treatments gave the largest yields of fiber in cu. mm. per stem for seedling field-grown flax plants. Mature field-grown plants gave the largest yields of fiber in cu. mm. per stem with the following treatments: 4–0–8, $CaCO_3$ 6000 pounds, 0–0–0, and 0–0–8. Medium high yields of fiber in cu. mm. per stem were obtained with the treatments 4–16–16 and 4–16–8.

A study of the various cultures leads to the conclusion that a fertilizer analysis closely approximating a 4–16–8 is the most desirable for fiber flax where little is known regarding the soil requirements.

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COMPETITIVE EFFICIENCY AND PRODUCTIVITY OF BLUEGRASS (*POA PRATENSIS* L.) WITH PARTIAL DEFOLIATIONS AT TWO LEVELS OF CUTTING[1]

L. F. GRABER[2]

That the frequency and extent of defoliations of forage plants is of much agronomic significance has been made evident by many workers in recent years This paper will report the results obtained from cutting a pure stand of weed-free bluegrass at two different levels or heights of cutting in 1929 and the effect of such defoliations on the productivity and the ingress of weeds in such bluegrass in 1930 and 1931.

Bluegrass seed was sown on a fairly fertile Miami silt loam soil on the University Farm at Madison, Wisconsin, at the rate of 100 pounds per acre on July 13, 1928. The soil was practically weed-free, having been fallowed during the season of 1927 and prior to seeding in 1928. Five days after seeding the plats were rolled twice with a 2-ton road roller which smoothed, levelled, and very firmly compacted the soil. All these treatments, along with favorable weather, resulted in a good uniform stand of bluegrass in the fall of 1928. No cuttings were made that season.

FERTILIZATION

In 1929, a portion of the bluegrass was divided into eight 1/100 acre plats. All of these plats were fertilized with a top dressing of potash

[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Received for publication September 30, 1933.

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(K_2SO_4)at the rate of 150 pounds of K_2O an acre and with superphosphate at the rate of 144 to 188 pounds of available P_2O_5 an acre in June 1929.

One-half of the plats (A and B) were treated with top dressings of nitrogenous fertilizers in 1929 on the following dates:

Apr. 13	200 lbs.	$(NH_4)_2SO_4$	per acre (40 lbs. N)
June 7	300 lbs.	Ammo-phos.	per acre (32 lbs. N)
Sept. 9	300 lbs.	$(NH_4)_2SO_4$	per acre (60 lbs. N)

On March 22, 1930, all plats were top dressed with 500 lbs. of ammonium sulfate per acre. This was the only fertilization given in 1930.

On April 18, 1931, the same plats (A and B) which were fertilized in 1929 were top dressed with 500 lbs. of ammonium sulfate (100 lbs. N) per acre and on May 16, 1931, with 400 lbs. of sodium nitrate (64 lbs. N) per acre.

Thus, in 1929, all plats of bluegrass were top dressed with abundant applications of phosphate and potash, but only one-half of the plats were fertilized with nitrogen. In 1930, none of the plats were fertilized with phosphate or potash, but all were treated with nitrogen. In 1931, only one-half the plats (A and B) received fertilizations and they consisted of heavy applications of nitrogen.

RAINFALL

The rainfall records for the growing seasons of 1929, 1930, and 1931 were taken from the Weather Bureau Office located about 3 miles from the experiment. The amount of such rainfall in inches was as follows:

	1929	1930	1931
April	4.29	2.95	1.97
May	1.31	4.23	1.74
June	4.35	6.60	3.05
July	8.02	2.84	2.10
Aug.	0.87	1.58	5.19
Sept.	3.17	4.79	7.17
Oct.	1.82	1.63	3.11
Total	23.83	24.62	24.33

CURRENT PRODUCTIVITY WITH TWO LEVELS OF DEFOLIATIONS

The partial defoliations during 1929 were accomplished with a lawn mower by clippings made on April 13 and 23; May 4, 18, and 31; June 12, 21, and 28; July 5, 15, and 24; and August 1 and 13, thus providing a total of 13 clippings for the season of 1929. However, one-half the plats, two fertilized (A) with nitrogen in 1929 and two not fertilized (C) with nitrogen that year, were clipped at a level of 1½ inches from the surface of the soil. Hereinafter this treatment will be referred to as "tall" clipping. The remaining plats (B and D) were clipped at a level of ½ inch above the surface of the soil and will be referred to as "close" clipping. The total yields of oven-dried bluegrass (practically all foliar portions) resulting from such clippings are given in Table 1.

TABLE 1.—*Pounds of oven-dried grass obtained with 13 clippings of bluegrass during 1929 taken at levels of ½ and 1½ inches.*

Fertilization, 1929	Cutting treatment, 1929, and plat	Lbs. per acre of oven-dried grass, 1929	Increase	
			Lbs.	%
Nitrogen	13 tall clippings (A)	2,939		
	13 close clippings (B)	4,516	1,577	54
No nitrogen	13 tall clippings (C)	993		
	13 close clippings (D)	2,547	1,554	156

Close clipping of the plats with nitrogenous fertilization produced 1,577 pounds or 54% more oven-dried grass an acre than clipping on the same dates and with the same frequency at the 1½-inch (tall) level. The plats not receiving nitrogen (C and D) in 1929 produced much less grass. With close clippings the yields were 1,554 pounds or 156% more than with taller clippings. However, all plats with "tall" clippings in which a remnant of 1½ inches of the foliar parts were unmolested produced a thick turf very free of weeds and foreign growth and very pleasing in appearance. In contrast, the close clippings produced a turf thin in appearance with much exposed soil, giving dispersed weed seeds an opportunity to establish plants in competition with the weakened bluegrass. Such results are made evident in Table 3. Under comparable conditions, weeds were from 5 to 7 times as abundant in 1930 with bluegrass given "close' clippings in 1929 as with the bluegrass given "tall" clippings that same year. The level at which the clippings were made was of far greater significance with reference to the ingress of weeds than the differences in fertilization (Table 3).

SUBSEQUENT PRODUCTIVITY

The relative effect of the two clipping treatments in 1929 on the subsequent productivity of bluegrass was measured in 1930. Before growth had started all plats were top dressed uniformly on March 22, 1930, with ammonium sulfate at the rate of 500 pounds per acre. There was a residual effect from the fertilization with ammonium sulfate on September 9, 1929, which is reflected in the larger yields of plats A and B in 1930 (Table 2). The plats of bluegrass (A) with "tall" clippings in 1929 and with nitrogenous fertilization in 1929 and 1930 were very vigorous and produced in the first cutting on May 10, 1930, 1,116 pounds more (74%) oven-dried grass than bluegrass given "close" clippings (B) in 1929. With the same defoliations but with bluegrass not fertilized with nitrogen in 1929, the increase on May 10, 1930, from the plats (C) given the "tall" clipping treatment in 1929 was 906 pounds, or approximately 85%.

SLOW RECOVERY REDUCES SUMMER PRODUCTIVITY

The second cutting of 1930 made on June 24 did not produce such increments in yield of the plats (A and C) given "tall" clippings in

1929. There was only an increase of 205 pounds or 10.5% in productivity for the plats of bluegrass designated A and a decrease of 355 pounds or 15% for the plats designated C. After cutting on May 10, 1930, a distinct difference was noted in rapidity of recovery made by the bluegrass which had been given "tall" and "close" clippings in

TABLE 2.—*Pounds of oven-dried grass obtained from bluegrass in 1930 and 1931 given "tall" and "close" clippings in 1929.*

Fertilization			Cutting treatment for 1929 and plats	Pounds of oven-dried grass per acre				
				1930				1931, June 14
1929*	1930†	1931‡		May 10	June 24	Sept. 15	Total	
Nitrogen	Nitrogen	Nitrogen	13 tall clippings (A)	2,617	2,143	431	5,191	2,890
			13 close clippings (B)	1,501	1,938	479	3,918	2,538
No nitrogen	Nitrogen	No nitrogen	13 tall clippings (C)	1,976	1,950	425	4,351	1,042
			13 close clippings (D)	1,070	2,305	488	3,863	873

*Apr. 13—200 lbs. $(NH_4)_2SO_4$ per acre (40 lbs. N)
June 7—300 lbs. Ammo-phos. per acre (32 lbs. N)
Sept. 9—300 lbs. $(NH_4)_2SO_4$ per acre (60 lbs. N)
†Mar. 22—500 lbs. $(NH_4)2SO_4$ per acre (100 lbs. N)
‡Apr. 18—500 lbs. $(NH_4)_2SO_4$ per acre (100 lbs. N)
May 16—400 lbs. $(NH_4)_2SO_4$ per acre (64 lbs. N)

1929. The more highly productive plats (A and C) on May 10 were much slower and less uniform in recovery than plats (B and D) which were less productive due to "close" clipping in 1929.

Probably there are many factors which are associated with such delayed recovery. Thus, a greater water utilization may lower the reserves of soil moisture sufficiently to delay recovery of the more productive plats. The shading of the newer leaves and the stimulation of growth extension by nitrogenous fertilization represents a considerable drain on the reserve foods of the more active portions of the rhizomes so that they may not function in recovery and subsequent top growth may be dependent upon the buds of the more dormant regions of the rhizomes.[3] It is also probable that the new leaves upon which immediate recovery depends are not only shaded but many of them are probably dessicated on sudden exposure to light after cutting. But whatever may be the cause or causes of delayed recovery it can be a most significant factor in the measurement of productivity of bluegrass throughout an entire season of growth.

[3]Graber, L. F., Food reserves in relation to other factors limiting the growth of grasses. Plant Phys., 6:43–72. 1931:
———, *et. al.* Insect injury of bluegrass in relation to the environment. Ecology, 12:547–566. 1931.

WEEDS COMPLICATE MEASUREMENTS OF SUMMER PRODUCTIVITY

Weeds also accounted in part for the much greater apparent productivity of plats of bluegrass B and D on June 24, 1930, than was made evident by the yields obtained on May 10, 1930. On this date weeds constituted no significant portion of the yield from any plat, but on June 24, 1930, they (mostly dandelions) were especially prevalent in the plats (D and B) clipped closely in 1929 (Table 3). Since they were not separated from the grass cut on June 24, 1930, they contributed much to the yields of plats designated D, in particular, and also plats designated B. All weeds were removed from each plat on August 7, 1930. Therefore, they did not contribute significantly to any of the yields taken in 1930 except those of June 24.

TABLE 3.—*Number of weeds per acre removed from plats on August 7, 1930.*

Fertilization		Cutting treatment		No. weeds per acre Aug. 7, 1930	
1929	1930	1929	1930	Dandelions	Others
Nitrogen	Nitrogen	13 tall clippings (A)	Three uniform cuttings on May 10, June 24, and Sept. 15 with field mower	17,050	5,150
		13 close clippings (B		107,400	2,150
No Nitrogen	Nitrogen	13 tall clippings (C)		18,750	1,650
		13 close clippings (D)		147,850	2,050

PRODUCTIVITY MEASURED IN 1931

Due to deficiencies in rainfall after June 24, 1930, the third cutting on September 15, 1930, produced only one-fourth to one-fifth as much oven-dried product as was obtained in each of the two previous cuttings. Although plats B and D had been clipped closely in 1929, they yielded somewhat better on September 15, 1930, than plats A and C given the more favorable clipping treatment the year previous. Perhaps the greater utilization of soil moisture during the early season by the most productive plats (A and C) may have caused a more severe subsequent deficit of water during the dry part of the summer than occurred in the plats with less productivity as measured by the combined yields of May 10 and June 24. This at least warrants consideration along with the factor of delayed and uneven recovery previously mentioned. However, the total yields for the three cuttings (Table 2) of 1930 were from 488 to 1,273 pounds (13 to 32%) more for the plats of bluegrass (A and C) which had been given "tall" clippings in 1929.

In 1931, the plats of bluegrass designated A and B were given very heavy fertilizations with ammonium sulfate (500 pounds per acre) on April 18 and sodium nitrate (400 pounds per acre) on May 16. With a deficit in the rainfall during April, May, and June the yields on

June 14 were not large. Plats A and C which were given "tall" clippings in 1929 produced from 14 to 20% more oven-dried bluegrass on June 14, 1931, than was obtained from plats B and D which had been given close clippings in 1929. It is interesting to note that the bluegrass in the heavily fertilized plats (A and B) did not recover after cutting on June 14, 1931, and remained brown and dormant (except for a narrow strip about the edge of the plats) for 10 weeks during the dry summer of 1931. With abundant fall rains recovery did occur, but the stand of grass was very uneven until very late in the fall of 1931. On the other hand, plats not fertilized with nitrogen in 1931 recovered promptly and uniformly after cutting on June 14, 1931, and while unproductive during the dry period of the summer, they were uniform and dense after the occurrence of fall rains.

SUMMARY

A much larger current production of oven-dried bluegrass was obtained with frequent and "close" defoliations than with "tall" defoliations at the same time and with the same frequency. The year following (1930), when productivity was measured by three uniform cuttings, the bluegrass which had been clipped closely in 1929 was less productive and weeds were 5 to 7 times more abundant. However, the increase in productivity during 1930 of the plats with "tall" clippings in 1929 occurred almost entirely in the first cutting on May 10, 1930. Because of many conditions associated with a rapid and abundant accumulation of top growth on such plats, delayed recovery reduced the yields of the subsequent cutting that year.

Where bluegrass of high potential productivity is stimulated by abundant nitrogenous fertilization and a satisfactory moisture supply, delays in recovery after cutting and removing a large quantity of top growth may greatly limit subsequent yields. This factor is significant in the selection of a system of cutting for measuring the maximum productive capacity of heavily fertilized bluegrass throughout an entire season of growth.

THE EFFECT OF POTASH ON STARCH IN POTATOES[1]

G. V. C. HOUGHLAND AND J. A. SCHRICKER[2]

The chief physiological function of potash in plants, according to literature and text books, is connected with the synthesis of starch and its translocation. Indeed, in one text (8)[3] the statement appears that the production and storage of starch in potatoes and sugar in beets is actually diminished in direct proportion to a decreasing supply of available potash in the soil. Likewise, in literature (3, 6, 10) somewhat similar statements are frequently found which assign to potash the same relation to starch formation. Granting that this relation exists in plants, it is clear that the rôle of potash in potato production assumes a very definite significance. In this regard it is only necessary to consider the different grades of fertilizer, all containing potash, now commonly used in the large potato-producing sections of this country to be convinced that the need for this plant food element in potato fertilizers is well recognized.

However, in view of the general belief that starch formation is intimately connected with the supply of available potash, it was considered possible that this particular fertilizer element might have even greater importance in potato production than has been heretofore attached to it. For instance, it was thought possible that some very interesting results could be obtained from potash experiments with potatoes which might eventually prove to be a valuable aid in regulating to some extent the starch content of tubers, with the idea of maintaining certain standards of quality recognized as desirable for various culinary purposes. In this regard it may be said that potatoes with a high percentage of starch are usually considered to be best for baking purposes, whereas those lower in starch content are as a rule more suitable for making French fried potatoes and potato chips.

OUTLINE OF EXPERIMENTAL WORK

In 1929, potash experiments were laid out at Onley, Va.,[4] on Norfolk sandy loam and at Arlington Farm, Rosslyn, Va., on soil locally termed Arlington clay loam. Both field experiments were planned and laid out by B. E. Brown of the Division of Soil Fertility, Bureau of Chemistry and Soils, as part of the soil fertility investigations with potato fertilizers. The writers are indebted to him for their use and for suggestions in connection with the present study.

In the details of the experiments provision was made for comparing muriate and sulfate of potash, in addition to a study of each material

[1]Contribution from the Division of Soil Fertility, Bureau of Chemistry and Soils, U. S. Dept of Agriculture, Washington, D. C. Received for publication October 7, 1932.

[2]Associate Soil Technologist and Junior Chemist, respectively.

[3]Reference by number is to "Literature Cited," p. 340.

[4]In cooperation with the Virginia Truck Experiment Station, T. C. Johnson, Director. The writers are also indebted to W. O. Strong, in charge of the Onley Substation, and to F. R. Reid, of the Division of Soil Fertility, Bureau of Chemistry and Soils, for assistance rendered during the course of the experiment.

applied in increasing amounts in complete fertilizers. There were also provided a number of check plats receiving no treatment and control plats treated with 6–8–0 fertilizer. All the potash-treated plats were run in duplicate and every year these duplicates, as well as all other plats at each location, occupied the same positions in the same field. Since the experiments were carried on for 3 years, an opportunity was thereby given to note any cumulative effects of the different treatments during this stage of the experimental period. Samples for starch analysis were taken at harvest each year. These were obtained by selecting 30 prime tubers at random from the center row of each plat while the dug potatoes were still on the ground, thus assuring representative samples composed of tubers from different hills. All tubers analyzed were U. S. No. 1 grade and slightly superior to market quality as they were carefully hand picked and stored at 40° F until analyzed a few days after digging.

ANALYTICAL RESULTS

The average percentages of starch in the potatoes from the different plats based on the results of the 3-year period are given in Table 1, along with the percentage of dry matter and starch-moisture ratio for each treatment. The variability of the data used to calculate the averages in Table 1 may be estimated from the values of the standard error given for each mean.

Considering first the starch percentages calculated on a dry basis, it will be noted that the results with 6–8–0 fertilizer, lacking potash, and those obtained by adding potash to the mixture regardless of amount or source, do not show a significant increase in the percentage of starch from the potash additions. Actual comparison of the figures shows that the largest increase in the percentage of starch from potash-treated plats over plats treated with fertilizer lacking potash in both experiments amounted to only 0.7%. On the contrary, in a majority of cases potash treatment apparently lowered the percentage of starch in the dry matter, but these differences can scarcely be considered significant.

Considering now the percentages of starch in the fresh potato pulp as given in Table 1, it will be seen that in every instance where potash was added to the fertilizer the percentage of starch was apparently lowered. At Onley, Va., with the exception of one case where 10% of potash derived from sulfate was added, each increase in the percentage of potash in the fertilizer was marked by a decrease in the percentage of starch in the potatoes. This relation was not so uniform at Arlington Farm, Va., yet the general tendency was the same. It also will be noted that the percentage of dry matter in the potatoes grown with 6–8–0 fertilizer lacking potash was higher than in any instance where potash was added to the mixture. In general, the trend of the percentage figures representing the dry matter followed closely those indicating the percentage of starch in the fresh potatoes. From these results it would seem that both the percentage of starch and dry matter in the potatoes were affected similarly by the potash additions. This relation would seem to be important from a quality standpoint,

because under such conditions a depression in the percentage of starch accompanied by a decrease in the percentage of dry matter produced an increasing starch-moisture ratio.

This ratio was calculated for all the potatoes from each plat. From these results, listed in Table 1, it appears that the starch-moisture ratio was increased whenever potash was added to the fertilizer, the maximum increase occurring at Arlington Farm, where a ratio 1:7.6 for the 6-8-0 plats was increased to 1:8.7 when 8% potash was added as muriate. In comparing muriate and sulfate of potash relative to their effect on the starch-moisture ratio, it will be found that, with only one exception, the potatoes grown with muriate showed higher ratios than did those from the corresponding plats treated with sulfate.

In summarizing the results given in Table 1 as influenced by additions of muriate and sulfate of potash to the fertilizer, it appears that neither potash material appreciably increased the percentage of starch in the potatoes, but on the contrary a depressing effect of both starch and dry matter was indicated, resulting in a higher starch-moisture ratio wherever potash was used.

During the 4-year period from 1928 to 1931 a number of potato samples taken from potash-treated and from no-potash plats located in the important potato-producing sections of the eastern states from Virginia to Maine were analyzed for starch. The results of these analyses were arranged in two groups, one the results from potash-treated plats and the other the results from treatment lacking potash. In classifying the figures no regard was paid to the percentage of nitrogen and phosphoric acid in the fertilizer or to variations in the percentage of potash when present. Substantially there were but two classifications, potash and no potash. The figures in these two groups represented, of course, the results of analyses from more than one variety. The majority of the early crop figures were obtained on Irish Cobblers, whereas Rural Russets, Smooth Rurals, and Irish Cobblers were about equally represented in the late crop analyses.

The average percentage of starch found in the dry matter where potash was applied in 131 cases to early potatoes was $60.4\pm.36$. On the other hand, where no potash was applied in 62 cases the average percentage of starch was practically the same, $60.8\pm.38$. With the late crop, potash applied in 115 cases gave an average of $68.3\pm.44$% starch, whereas no-potash treatment in 40 cases gave an average of $68.9\pm.76$% These comparisons can be regarded as highly representative, since it is plain they reflect the influence of potash on the percentage of starch in tubers grown under actual field conditions over a period of 4 years on many different soil types and subjected to the effects of a variety of seasonal conditions. If it were usual under these conditions for an increase in the percentage of starch in potatoes to result from the use of potash, it seems only reasonable to expect the averages of the analyses given above to show this effect. However, the data compiled from two separate experiments and where general averages from widely separated fields were taken do not show consistent increases in the percentage of starch in potatoes induced by applications of potash.

TABLE 1.—*Average percentage of starch and dry matter and starch-moisture ratio in Irish Cobbler potatoes grown with fertilizers containing different amounts and sources of potash, 1929–31.*

Treatment*	Muriate of potash				Sulfate of potash			
	Starch,† dry basis, %	Starch, moist basis, %	Dry matter %	Starch-moisture ratio	Starch, dry basis, %	Starch, moist basis, %	Dry matter %	Starch-moisture ratio
				Onley, Virginia				
6–8–0	63.4±0.9‡	11.4±.11	17.9	1:7.2	63.4±0.9	11.4±.11	17.9	1:7.2
6–8–4	62.7±1.5	10.7±.25	17.1	1:7.7	63.6±1.2	11.0±.10	17.3	1:7.5
6–8–6	62.7±1.1	10.5±.19	16.7	1:7.9	64.1±1.8	10.7±.30	16.7	1:7.8
6–8–8	63.5±2.0	10.3±.24	16.2	1:8.1	64.1±2.5	10.4±.22	16.2	1:8.0
6–8–10	61.9±2.2	10.1±.30	16.3	1:8.3	63.5±1.3	10.9±.26	17.2	1:7.6
Nothing	63.5±1.2	11.0±.25	17.3	1:7.5	63.5±1.2	11.0±.25	17.3	1:7.5
				Arlington Farm, Virginia				
6–8–0	59.3±0.5	10.8±.26	18.2	1:7.6	59.3±0.5	10.8±.26	18.2	1:7.6
6–8–4	58.1±1.2	9.9±.48	17.0	1:8.4	60.0±0.9	10.6±.51	17.7	1:7.8
6–8–6	59.4±0.8	10.1±.43	17.0	1:8.2	58.4±0.8	10.0±.23	17.1	1:8.3
6–8–8	57.6±1.2	9.6±.65	16.7	1:8.7	58.4±1.4	9.9±.51	17.0	1:8.4
6–8–10	59.2±1.4	10.0±.63	16.9	1:8.3	58.8±0.5	10.5±.33	17.9	1:7.9
Nothing	60.1±0.5	10.4±.19	17.3	1:7.9	60.1±0.5	10.4±.19	17.3	1:7.9

*2,000 pounds per acre. †Herle's (2) saccharimeter method. ‡Standard error of mean.

From observations of the crops growing on the different plats, especially in Maine and at Onley, Va., it was noticed that invariably the treatment lacking potash produced potato plants exhibiting one or more of the characteristic symptoms attributed to "potash hunger" (7). These evidences of need for potash usually became more pronounced on the no-potash plats the second and third years, when, at Onley, Va., the vines showed unmistakable symptoms of nutritional disturbance, although the percentage of starch in the tubers was higher in every case where potash was omitted than it had been on the same plats during the previous 2 years. It was also observed that the color of the vines where potash was used invariably took on a light green shade, especially noticeable on the plats receiving muriate of potash.

The experimental plan and the results obtained in the present investigation closely parallel the recent work of Tomzig and Pernice (9) in East Prussia. They found that the use of either muriate or sulfate of potash alone or in mixtures with nitrogen and phosphoric acid depressed the percentage of starch in potatoes; but due to its chlorine content, muriate of potash caused a greater depression than sulfate. In arriving at these conclusions not only was the percentage of starch obtained by using complete fertilizers compared with the results from fertilizer containing only nitrogen and phosphoric acid, as was done in the present investigation, but in addition they compared the results from potash alone with the percentage of starch in potatoes grown on unfertilized plats. They also found that nitrogen and phosphoric acid did not alter the percentage of starch, as their average results from unfertilized plats and those treated with only nitrogen and phosphoric acid were practically identical. These investigators likewise noted a lighter green color of the vines on plats treated with muriate of potash and this they attributed to an alteration of the normal water content of the leaf, as shown by Dhein (1), and not to a reduction in the amount of chlorophyll.

It is possible, of course to get an increase in total starch produced without necessarily altering the percentage of starch in the tubers. However, it should be recognized that figures showing the calculated total amount of starch produced are more directly influenced by the size and number of tubers and all other conditions affecting yield than the percentage figures which, in the opinion of the writers, give a more satisfactory indication of the effect of treatment on starch elaboration. Nevertheless, the average total amount of starch produced by each treatment given in Table 1 has been calculated from the total crop yields and the results presented in Table 2. The significance of the results has been interpreted by the use of Student's method as described by Love and Brunson (4), making paired plat comparisons for each year. The odds for significance have been taken from tables prepared by Love (5). Odds of less than 30:1 were considered not significant.

At Onley, Va., none of the potash additions to the fertilizer gave an increase in starch yield with odds of 30:1 when comparison was made with the yield from 6–8–0 treatment. At Arlington Farm, Va., there were only two treatments, 6–8–4 and 6–8–10 with sulfate of potash,

that gave odds greater than 30:1, although all of the plats treated with sulfate of potash gave comparatively large increases. It is probable that the failure of the results to show significance in these particular instances may have been caused by a differential seasonal response brought about by the difference in the total salt content of the fertilizers compared.

In comparing the effects of the two potash materials on the starch yield at both locations, sulfate of potash shows a greater tendency toward increasing it than does muriate of potash, although the significance of the increases in all but two cases leaves much to be desired. As the experiment continues it can be reasonably expected that the variability will be reduced and the odds of certain treatments probably increased.

TABLE 2.—*Pounds of starch produced per acre with Irish Cobbler potatoes grown at Onley and at Arlington Farm, Va., using fertilizers containing different amounts and kinds of potash salts, 1929-31.**

Treatment†	Onley, Virginia			Arlington Farm, Virginia		
	Average yield, pounds	Increase over 6-8-0, pounds‡	Significance in odds	Average yield, pounds	Increase over 6-8-0, pounds‡	Significance in odds
6-8-4 (KCl)	1,222.6	+34.3	1.9:1	1,224.0	+164.0	13.2:1
6-8-6 (KCl)	1,278.6	+90.3	8.7:1	1,337.0	+277.0	13.5:1
6-8-8 (KCl)	1,197.6	+79.0	2.0:1	1,113.6	+ 48.3	4.3:1
6-8-10 (KCl)	1,113.3	— 5.3	<1.2:1	1,116.6	+ 51.3	7.1:1
6-8-4 (K_2SO_4)	1,220.6	+81.6	24.2:1	1,551.3	+194.0	419.0:1
6-8-6 (K_2SO_4)	1,196.0	+57.0	1.3:1	1,583.0	+225.7	13.9:1
6-8-8 (K_2SO_4)	1,071.3	—33.7	2.1:1	1,574.0	+374.3	14.6:1
6-8-10 (K_2SO_4)	1,087.3	—18.0	1.4:1	1,558.3	+358.6	30.8:1

*Average of three seasons' results with duplicate plats each season.
†2,000 pounds per acre.
‡The averages of the two nearest 6-8-0 plats were used for comparison.

SUMMARY

Starch analyses were made on samples of potatoes taken from potash experiments located at Onley and at Arlington Farm, Va. Three-year averages of the results of these analyses did not show significant increases in the percentage of starch induced by applications of complete fertilizers containing as much as 10% potash. Furthemore, when the average analyses of potatoes from potash-treated and from no-potash plats for both early and late crops were compared, no significant increases in the percentage of starch were found in potatoes grown on the potash-treated plats. On the contrary, in a majority of cases, potash additions to the fertilizer caused a slight depression in the starch percentage and in this regard muriate of potash seemed to have a greater effect than sulfate.

Likewise, the potash additions depressed the percentage of dry matter in the potatoes, thus bringing about an increase in the starch-moisture ratio in nearly every case corresponding to the amount of the potash addition. This ratio was higher when muriate of potash was substituted for sulfate.

It was suggested that the effect of potash on the relationship between the percentages of starch and moisture in the potatoes is important from a culinary standpoint.

The 3-year averages of the total starch yield produced at Onley,. Va., did not show a single increase from potash applications with odds of 30:1. However, at Arlington Farm, Va., only the 6–8–4 and 6–8–10 treatments with sulfate of potash gave increases in total starch with odds of more than 30:1.

From the results of more than 300 starch analyses of potatoes grown on soil in one case treated with fertilizer lacking potash and in the other subjected to potash treatment varying in amount and source, it appears that the possibility of regulating to any great extent the percentage of starch in potato tubers through altering the amount of available potash is but slight. The results of these investigations plainly indicate, in view of the marked differences in color and growth of the potato vines on the potash-treated and no-potash plats, that the relation between potash and starch formation may well be subjected to a critical study before the actual effect of potash can be fully determined.

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INFLUENCE OF CHEMICAL COMPOSITION OF ORGANIC MATTER ON RATE OF DECOMPOSITION[1]

THOMAS L. MARTIN[2]

The organic matter of the soil consists of fresh material, intermediary products, resistant material, and newly synthesized products consisting largely of dead and living cells. When organic matter is added to the soil, decomposition begins and CO_2, NH_3, and NO_3 accumulate. Easily decomposable parts disappear quite readily and resistant material is left. This and the re-synthesized resistant material constitute the staple soil organic matter. The rapidity of the decomposition depends upon the kind of organic matter, the type of organisms involved, and the environmental conditions under which the decay process occurs.

To determine the rate of decomposition, the two criteria, CO_2 evolution and NO_3 accumulation (1,2,3)[3], have been used as measures. While these measures do indicate in general the rates of decomposition, yet the amount of CO_2 evolved is not a complete index (6), for much of the C is utilized by the micro-organisms engaged in the decay process and micro-organisms differ in the amounts of C they can utilize (7).

Neither should one place too much confidence in NO_3 accumulation as a measure of decay, because organisms differ in the amount of N they use for protoplasmic building (7). This causes a variation in the amount of ammonia available for the nitrification process.

The nature of the organic matter has its influence on the activities of the micro-organisms. Plant substances low in nitrogen yield very little free NH_3 or NO_3, even though considerable decomposition may take place (8).

The ratio of C to N in organic matter has been used to explain why one organic matter decomposes more rapidly than another (4,5). The wider the ratio, the slower the rate of decay because of the lack of C to meet the synthetic needs of the organisms. Conversely, the narrower the ratio, the more rapid the decomposition because of a plentiful supply of C and N to meet these needs.

The C-N ratio theory does not always hold. Waksman and Tenny (10) have found that, although oak leaves contain more N than corn stalks, yet the decomposition was considerably slower in the oak leaves. The rate was about that of rye straw which contained proportionately about one-third or less N than did the leaves. Even the addition of available N did not hasten the decomposition of the oak material. The lignin content of the oak leaves was probably responsible for the delayed decay. Lignin unites with cellulose which prevents the decomposition of the cellulose and slows up oak leaf decay. However, oak leaves contain tannin which is toxic to micro-organisms. This, too, perhaps contributes to retarded decomposition. However,

[1]Contribution from the Department of Agronomy, Brigham Young University, Provo, Utah. Received for publication September 6, 1932.

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[3]Reference by number is to "Literature Cited", p. 345.

it is to be noted that the nature of the organic material as well as the type of organisms at work are important factors which determine the rate at which decomposition takes place.

The writer (1) has made a study using CO_2 evolution and NO_3 accumulation as measures of the rate of decay of alfalfa and sweet clover roots and tops. Sweet clover and alfalfa tops and alfalfa and sweet clover roots have evolved CO_2 and accumulated NO_3 in the order named. If these measures were completely dependable, one would conclude that these substances decomposed at rates indicated by this order. However, in these experiments, the nature of the organic matter and the types of organisms doing the work were not considered. These factors should be taken into account if one is to have a reasonably comprehensive picture of organic matter decomposition.

In making such studies one needs to know the chemical and structural nature of the material added to the soil; what changes occur in the chemical constituents as decomposition proceeds; and what is contributed to the soil humus by each type of organic matter In order to consider the effect of the organisms when all of these factors were fully considered the following experiment was carried out.

METHOD OF PROCEDURE

Alfalfa tops 18 inches high were dried and ground. Alfalfa roots were also dried and ground. The alfalfa was obtained from a 5-year-old alfalfa field. Sweet clover tops were secured from a 2-year growth of sweet clover when the tops were 12 inches high and the roots were obtained to a depth of 12 inches. They were dried out and ground. Fresh materials were analyzed and other quantities were incubated with 200% moisture at room temperature and were then analyzed after 30-, 90-, 210-, and 270-day incubation periods. Waksman and Stevens' (9) method of analysis was used in which materials soluble in ether and alcohol, hot and cold water, 2% HCl, and 80% H_2SO_4 were determined, also the crude protein and the ash. The ether and alcohol extracts contain the oils, fats, waxes, resins, chlorophyll, etc. The hot and cold water soluble materials consist of sugars, amino acids, soluble proteins, starches, organic acids, ash, etc. The HCl and H_2SO_4 extracts were the hemicellulose and cellulose fractions, respectively. The residue left after filtering the H_2SO_4 extract was considered as the lignin fraction. The total N, minus the N in the hot and cold water soluble material, multiplied by 6.25 is recorded as the crude protein.

RESULTS

The results of these determinations are recorded in Table 1.

The analyses presented in Table 1 are the averages of duplicate determinations. It will be noted that the fats in the alfalfa tops, as recorded in the ether and alcohol soluble extract, do not decrease significantly. This too, is the case with the alfalfa and sweet clover roots. The sweet clover tops, however, seem to have shown a consistent and perhaps significant decrease. A variation in the rate at

which fat decomposes may be due to the kind of complexes of which the fats are composed (6). Some of these complexes decompose readily, while others resist decomposition. The fat in alfalfa and corn stalks decompose quickly while fat in straw resists disintegration. The fats and waxes soluble in ether are decomposed slowly by micro-organisms and may even accumulate (10).

TABLE 1.—*Percentage composition of alfalfa and sweet clover at different periods of incubation.*

	Fresh material	Incubation period			
		30 days	90 days	210 days	270 days
		Alfalfa Tops			
Ether and alcohol soluble	5.93	6.50	8.66	4.06	6.08
Hot and cold water soluble	36.02	17.09	7.20	3.89	3.66
Hemicellulose	4.13	5.50	3.50	6.30	5.68
Cellulose	9.41	13.00	9.20	6.80	10.11
Lignin	9.06	17.20	19.80	21.60	20.02
Crude protein	13.70	14.50	12.31	11.63	9.77
Ash	9.00	12.70	26.80	25.80	24.40
		Alfalfa Roots			
Ether and alcohol soluble	4.51	4.12	2.68	4.12	6.26
Hot and cold water soluble	33.63	27.10	4.37	2.86	3.80
Hemicellulose	10.04	9.70	8.70	4.13	7.66
Cellulose	13.10	21.60	17.80	12.5	13.10
Lignin	11.84	12.00	33.00	29.51	25.39
Crude protein	4.40	4.13	4.50	4.68	2.45
Ash	11.60	12.30	21.10	25.10	20.18
		Sweet Clover Tops			
Ether and alcohol soluble	6.20	---	3.76	3.08	2.90
Hot and cold water soluble	42.80	33.90	29.05	24.60	15.50
Hemicellulose	11.89	3.50	7.00	4.14	5.05
Cellulose	8.16	9.20	19.01	16.70	16.70
Lignin	6.75	19.80	19.60	16.70	28.20
Crude protein	7.00	12.31	6.10	12.37	9.40
Ash	11.45	18.60	28.60	21.14	27.60
		Sweet Clover Roots			
Ether and alcohol soluble	3.16	———	3.59	3.28	4.10
Hot and cold water soluble	23.70	25.00	16.10	12.80	8.50
Hemicellulose	18.73	8.70	10.01	5.70	6.60
Cellulose	12.63	17.80	29.03	33.90	20.71
Lignin	12.91	31.00	23.40	28.60	26.26
Crude protein	4.90	4.50	5.60	5.10	2.14
Ash	11.51	17.50	25.22	21.14	17.70

The hot and cold water soluble matter has decreased in all the material. This decrease was relatively rapid for the alfalfa tops and roots. More than half of this material had disappeared by the end of 30 days in the case of alfalfa tops, and for both tops and roots the destruction was nearing completion by 90 days. In sweet clover tops and roots, the water-soluble material did not decrease so rapidly, and in 9 months had not been as completely used up as had this material in the alfalfa in 3 months. However, the decrease is consistent

throughout. These materials—sugar, soluble proteins, starches, organic acid—are used quite readily by the soil micro-organisms.

The hemicellulose fraction has shown a tendency to disappear quite uniformly throughout the decomposition periods, especially in the roots of both legumes which change rather similarly. The tops are not so consistent. These materials furnish readily available energy for bacteria.

Crude proteins in all the material studied tend to remain constant, with the tops containing several per cent more than the roots in each case.

As long as C is available in organic material there will be a building up of microbial protoplasm (10). In the roots the crude protein is less than in the tops and does not increase as decay proceeds. The percentage of lignin and cellulose is also higher. It may be that there is less C available in the roots and consequently the rate at which microbial protoplasm is developed is retarded. If this experiment could be run for a longer period of time, the degradation of proteins would occur because of the lack of available carbohydrates. This is apparently indicated to be the tendency in the case of the roots during the final period of this experiment when there was a decided drop in crude protein for both alfalfa and sweet clover.

This may be the explanation for the resistance of proteins to the decomposition process. There is probably some new protein material built up during the decay period, the larger part of it being microbial protoplasm (11). One would expect that this should decompose readily. It might be that this microbial material assumes a colloidal state which is more resistant. A physical state might explain the resistant tendencies and, therefore, the resistance to decay as noted in Table 1.

The lignin content shows a decided increase in amount during the early part of the experiment, after which it tends to remain constant. Since some of the other materials are being lost rapidly, lignin tends to accumulate and is the principal contribution to soil organic matter. This is the case in the tops and roots, and particularly so with the roots.

Cellulose seems to have resisted decomposition more than any other material, with the exception of lignins. Alfalfa is less resistant than sweet clover. In alfalfa, after the first 30 days, the tops and roots decrease uniformly, while in sweet clover tops and roots there is a decided increase after 30 days. Lignin is thought to delay decomposition of cellulose because of the formation of ligno-cellulose (6). In the present experiment the increase in lignins does not follow very closely the decomposition rate of cellulose. There is a slow decomposition of cellulose in alfalfa roots and tops which indicates retarded decay due to the presence of much lignin, but in sweet clover tops the lignin content is almost as high as in alfalfa tops, yet there is an actual percentage increase in cellulose. The same conditions prevail with the roots. Cellulose decomposes slowly in alfalfa roots, but in the sweet clover roots there is noted a decided increase in cellulose content as decay proceeds. It seems in a general way that retardation occurs due to the lignin content, but when sweet clover is compared

with alfalfa there is a distinct difference. There seems to be something in sweet clover in addition to lignins which delays the decomposition of cellulose.

The crude protein, according to Waksman and Tenny (11) and others, decreases at a very low rate so that toward the end of the decomposition period the principal material left is the lignin and the re-synthesized nitrogenous material. Table 1 indicates the same tendency, except that up to the end of this 9-month experiment there was also still a very significant accumulation of cellulose in the case of the sweet clover tests. Waksman and Tenny (11) found that when materials are added to the soil, the plant constituents tend to disappear in the following order: Water-soluble substances followed by part of the hemicellulose, then the cellulose and hemicellulose. The lignin resists decomposition and accumulates. The crude protein builds up from the C liberated and the N available. This protein material then tends to diminish slowly compared with the rate of decomposition of the balance of the constituents, save lignin, and this makes the soil organic matter consist largely of resistant proteins and lignins.

CONCLUSION

The results of this experiment agree with the findings of Waksman and others, except that the sweet clover cellulose does not break down nearly as readily as does the crude protein. The water-soluble materials in the roots and tops disappear rapidly and at about the same relative rates for organic material from the same source, but the disappearance is more rapid for alfalfa than for sweet clover. Alfalfa tops and roots seem to decompose more rapidly than do sweet clover tops and roots. The lignin content accumulates very rapidly, more so in roots than in tops. Due in all probability to a higher percentage of lignin in the roots and to its tendency to arrest decay of cellulose, tops decompose at a more rapid rate than do the roots.

Because of the slow decomposition of proteins and the rapid accumulation of lignin, there is the suggestion that the remainder will consist largely of these two substances. However, in the sweet clover tops and roots cellulose probably too will be a part of the residue.

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SOIL REBUILDING AT THE RED PLAINS EROSION STATION[1]

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The Red Plains Soil Erosion Experiment Station is located in central Oklahoma, about 4¼ miles south of Guthrie. The Red Plains region comprises some 36 million acres, chiefly in Oklahoma and Texas. It is characterized by gently rolling inter-stream divides, with strips of more rolling country extending several miles back from the principal streams. In the more rolling parts of the region the original smooth-surfaced slopes have been changed in detail by gully incisions in almost countless instances. Every field which has been cultivated for periods of as much as 10 to 15 years shows small or large areas of erosion-exposed subsoil, which is very much less productive than was the original topsoil. The combination of one-crop agriculture, torrential rains, extremely erosive soil, and general neglect of the land with respect to protection by tenant farmers has resulted in widespread erosion. In numerous instances fields have been completely ruined by severe erosion, even whole farms. An erosion survey of the nation brought out the fact that erosion is particularly severe in this region. This station was the first one established under the national program of soil conservation inaugurated about 3 years ago.

THE STATION FARM

The station farm is typical of the rolling part of the Red Plains. The soils are of two principal types, *viz.*, Vernon fine sandy loam on the slopes and Kirkland fine sandy loam on the level positions. The latter type has a tough, dense subsoil, developed through a long period of soil-building processes where, owing to the protection afforded by its smooth position, the soil has received the full impress of climatic influences. The Vernon fine sandy loam, on the other hand, has a comparatively friable subsoil. This is a youthful soil in the pedological sense, and is subject to severe erosion owing to its

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, in cooperation with the Oklahoma A. & M. College. Received for publication September 10, 1932.
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physical character and sloping position. These soils are both derived from sandstone interbedded to some extent with shales. They are naturally rather low in plant food.

When the station farm was taken over in 1929 a detailed erosion survey revealed the fact that the 70 acres which had been cleared and brought into cultivation since 1889 had suffered a soil (and subsoil) loss of 1,900 tons per acre, or about 50 tons per acre per year for the 40-year period since the first plowing. This represents a layer almost 1 foot deep over the entire 70 acres. That portion of the farm which had remained in grass and woods had not suffered.

Approximately 100 acres of the 160 in the farm are now under cultivation, the rest consisting of wooded areas and abandoned gullied land.

THE STATION PROGRAM

The work of the station is carried out under a three-way cooperative arrangement between the U. S. Dept. of Agriculture, the Oklahoma A. & M. College, and the Guthrie Chamber of Commerce. The station is operated under the supervision of the author, representing the Bureau of Chemistry and Soils, and specialist in soils and agronomy. The engineering phases of the work are under the direction of H. S. Riesbol, of the Bureau of Agricultural Engineering. Messrs. W. Guy Kincannon and Henry Bergschneider represent the Oklahoma A. & M. College. Analyses of rainwater, run-off water, eroded material, and cottonseed are carried out in the A. & M. laboratories at Stillwater, as well as threshing, ginning, and cotton fiber tests. Various soil samples are sent to the Washington laboratories for physical and chemical analyses.

The investigations fall under three major groups, as follows: (1) Fundamental studies of erosion and run-off rates, fertility losses, and the processes involved, under various condition of slope and cropping and tillage practice; (2) experimentation with various vegetative and artificial means of erosion control; and (3) soil rebuilding after depletion by erosion. Under the first head the effects of such factors as length of slope, crop rotations, sod and forest covers, bare surface condition, absence of topsoil, fall and winter plowing, and burning off of woodlands are being quantitatively measured in terms of run-off, wash-off, plant food losses, and crop yields. Along with these measurements are determined also the precise effect of crops, rotations, tillage methods, and terracing on moisture conservation.

Under the second heading the effectiveness and cost of strip cropping, contour cultivation, and various other adaptions of cropping and tillage methods, subsoiling, terracing, and the building of dams as implements of erosion control are being worked out.

BASIC STUDIES

Twelve plats, occupying a 7.7% slope, are comprised in a major set-up of plats (control plats) where all the run-off and soil wash-off are collected in large concrete tanks at the lower ends, built to hold the run-off from the greatest recorded rainfall for the region. This

makes possible the absolute measurement of water, soil, and fertility losses from definite areas caused by a definite amount of rain falling over a given period of time.

Three of these plats are planted to cotton continuously. With respect to length they are short, medium, and long, the medium length plat being twice as long as the short plat and half the length of the long plat. Since the upper ends are protected from intake of rainwater, these areas afford measurements of what would take place on slopes of the same gradient occupied by the same soil, for the same length of ground, whether the up-slope protection is affected by a terrace, rock wall, or any other water-proof barrier. The only difference is that at the very lower end the water and soil go over into a vat instead of being piled up on the ground, where no very accurate measurement of the downhill translocation of the soil could be made.

Three plats of medium length (72.6 feet) are devoted to a rotation of cotton, wheat, and sweet clover. Results from this are showing the tremendously important rôle crop rotations take in the matter of minimizing the effects of erosion. This experiment, so far as it has gone, shows that four times as much soil is lost from the same slope and soil where cotton is grown continuously as from this rotation. Moreover, the losses of water and soil from cotton are much less under the latter situation, and the yield of cotton is considerably larger.

Another medium-length plat is set to Bermuda grass. This has shown an average water loss of less than 2% of the precipitation, with almost no soil loss. On another plat of the same size, where no vegetation is permitted to grow, about twice as much water is lost as from land cropped year after year to cotton, but about 10% less soil. Here the soil loss exceeds that from Bermuda sod by more than 300 times.

Where all the topsoil has been removed, down to clay subsoil, and the land planted to cotton, the run-off and soil loss have been about double the corresponding losses from cotton grown continuously where the topsoil still remains.

Burning off the forest litter annually has resulted thus far in increasing the run-off 30 times and the soil loss 15 times, as compared with an unburned area having the same soil, slope, and forest cover.

RELATION OF EROSION TO YIELD AND QUALITY OF COTTON

Studies of the effects of erosion on yields and quality of cotton have shown that excessive washing delays the blooming and maturity of cotton about 10 days, lowers the yields about one-half or more, and reduces the length of the staple by 1/32 to 2/32 inch. The lint is also weaker in the case of cotton from deeply eroded soil and the cottonseed yields a considerably lower percentage of oil.

RELATION TO MOISTURE

Moisture studies indicate that on the Vernon fine sandy loam of this part of Oklahoma closed-end level terraces effect a large saving of moisture, but the crops in the terrace-channels have been so damaged by standing water that this type of terrace can not be recommended

upon the basis of the results thus far obtained. The results to date indicate that on this soil graded terraces do not effect any considerable saving of moisture, their principal contribution relating to conservation of soil.

EROSION CONTROL STUDIES

Studies of various methods of erosion control are indicating that contour cultivation and strip cropping on the Vernon fine sandy loam are both effective and very practicable. Contoured cotton on a quarter acre plat (6% slope) has lost only one-half as much soil as an adjoining plat with the rows up and down the slope. The yield was 6.2% higher for the contoured area.

Four 1-acre fields (4% slope) were put into strip cropping this year. The cotton was listed (bedded) in on the contour and the thick-growing, soil-saving strips were planted to oats and Sudan grass. The row crop and soil-saving strips each occupy approximately half of the land. With one of the most intense rains (May 31, 1932) since the establishment of this station, it was observed that this method of farming almost completely stopped soil losses and very largely diminished run-off, admirably demonstrating its efficiency and practicability.

The terrace studies carried on by representatives of the Bureau of Agricultural Engineering have as their object the determination of the correct grade and spacing, permissible length, and cost of construction and maintenance on badly gullied land, slightly eroded land, and freshly broken virgin land; as well as the efficiency of various types of terraces in erosion control. These investigations relate also to gully control with various types of pole, brush, rock, and wire dams; and to the cost of these dams. From the accurate records of this work information will soon be available for the farmers of this region. There are about 10 miles of terraces on the erosion farm.

Bermuda-grass dams have proved effective in the control of small gullies, but some farmers object to starting this persistent grass anywhere on their lands. With light application of superphosphate sweet clover has caught very well in an experiment dealing with a large gully, and shows promise of being a useful implement in controlling these major ravines.

Subsoiling has not as yet shown any profitable increase in yields, but the experiments are being continued in order to determine definitely the full significance of this tillage method.

Practical possibilities of reclaiming badly eroded land are being investigated on small plats undergoing various cropping, tillage, and fertilizer treatments. This phase of the work will be carried on on a field scale, where small-gully control agencies, check dams of various kinds, terracing, and the growing of soil-saving crops will be employed. The possibilities of lime, fertilizers, crop rotations, legumes, and winter cover crops(wheat, rye, vetch, and Austrian peas) in bringing back badly eroded land are being determined, the results being measured in terms of costs and yields.

The effect of terracing on crop yields, the practicability of crossing terraces at right angles in cultivation, and the relation of mulching to

moisture conservation are among the other phases of experimental work at the station.

Recently, a very badly eroded farm of some 120 acres adjoining the station farm has been acquired and work is being done to ascertain the practical possibilities for reclaiming land of this kind for pasture purposes by means of cheap gully control with rock, pole, and brush dams and by the use of shrubs, grass, vines, and trees, such as are available on the regional farms. There are in Oklahoma some 2 million acres of such land which, though once farmed, is now practically abandoned as the result of excessive erosion. These devastated lands, once fertile and valuable, probably can not be economically reclaimed except for pasture use or for forestry.

An interesting combination of wheat and rye for winter pasturage and erosion control is being tried. In this experiment wheat is sown on the contour in the fall. It affords considerable pasturage and slows down erosion. In the spring of 1932, several weeks before corn planting time, rows 40 inches apart were listed across a field thus treated, on the contour, using a lister with the mold boards removed and plowing 3 or 4 inches deep. A strip about 8 inches wide was opened up in the spring of 1932 and the wheat removed. The small furrow thus developed acted as an added agency of erosion control, caught rainwater and thereby conserved additional moisture, permitting the planting of corn in a favorable seedbed. When the corn came up, the field was run over with a disc cultivator, which threw the dirt away from the corn, covering up the wheat. In subsequent cultivations the wheat was entirely removed. Under this system pasturage is afforded by the wheat until the corn is up. Cotton was similarly planted in rows listed across the wheat. Just how well this method may fit into central Oklahoma conditions remains to be seen, but the first year's results are suggestive of practical possibilities.

A number of small plats have been planted to various grasses in an effort to ascertain their precise value in connection with the erosion control problem.

PHOSPHATE AVAILABILITY IN ALKALINE CALCAREOUS SOILS[1]

W. T. McGeorge[2]

Practically all the cultivated soils in the irrigated valleys of Arizona are calcareous. That is, they contain 2 to 10% of $CaCO_3$. On the whole these soils are well supplied with phosphate and as measured by various chemical solvents it is shown to be present in readily available forms. In spite of this fact crops usually respond to phosphate fertilization on these same soils. It is evident from this that solubility is not a measure of availability in calcareous soils. It is the purpose of this paper to present a brief discussion of some important developments in the study of phosphate availability at the Arizona Agricultural Experiment Station[3] as applied to calcareous soils and to point out that too little attention is being given to the relation of certain soil peculiarities to the absorption of phosphate by plants.

The soil types under discussion range in reaction from pH 7.8 to 9.4 or higher. The range of least phosphate solubility in these soils is pH 8.0 to 8.5, such soils usually yielding no water-soluble phosphate by the Deniges method. Above pH 8.5 the hydroxyl ion comes into play as an active aid to solution and as a result all black alkali soils contain an abundance of phosphate in the soil solution.

In studying phosphate availability in these soils one of the first observations was the greater response to phosphate in the soils of least desirable physical texture. In fact there was an astonishingly close inverse relation between the percentage of clay in the soil, the amount of puddling, and the degree of fertility as measured by response to phosphate fertilization. Later, it was observed that there was less response to phosphate fertilization after these soils had been leached and that under field conditions "ponding" water upon them until the soil broke to let the water through partially restored their fertility. While the availability of phosphate was shown to be reduced by salts, the amounts leached out of the soils were not sufficient to explain entirely the difference in fertility. Then again, fixation and reversion studies showed that puddled soils fixed phosphate more rapidly and more strongly than soils of good physical texture. Without a doubt there is some characteristic of puddled soils which is instrumental in depressing the availability of phosphate. A deficiency of carbon dioxide in the soil environs seemed to be the most logical explanation.

Previous studies had led us to question the presence of any carbon dioxide in alkaline soils. In fact it should be self-evident that free carbon dioxide cannot exist in the presence of hydroxyl ions. Pursuing the study of phosphate availability on this basis, some interest-

[1]Contribution from the Department of Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz. Also presented at the meeting of the American Chemical Society held in Denver, Colorado, August 22, 1932. Received for publication October 6, 1932.
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[3]Ariz. Agr. Exp. Sta. Tech. Buls. 35, 36, 38, 40, 41, 42. 1931–32

ing and different aspects of phosphate nutrition were disclosed. There can be no assimilation of phosphate from a calcareous soil in the absence of carbon dioxide and since arid soils are very low in organic matter, exudation from plant roots is the main source. Where aeration is restricted, carbon dixoide exudation may become toxic. In order that carbon dioxide function properly, a certain balance between carbon dioxide and oxygen must exist. An excess of carbon dioxide may do just as much damage as a deficiency, for it will stop all root elongation. When the root penetrates a puddled layer of soil its elongation is so greatly retarded that the exuded carbon dioxide may reach toxic proportions, partly because of the retarded elongation and partly because of the limited diffusion in a puddled soil. Thus all the exuded carbon dioxide remains within the film immediately surrounding the root tip and we have demonstrated the toxicity of such a condition. But in addition we have demonstrated, by water culture, that there is no absorption of phosphate in the presence of an excess of carbon dioxide. Thus, the relation of aerated and puddled soils to phosphate nutrition is self-evident. The proper balance between carbon dioxide and oxygen is impossible in a puddled soil because of restricted diffusion. With practically no organic matter, anaerobic conditions, and little root growth, there can be little or no carbon dioxide in the environs of a puddled soil.

The chemical relations associated with the manner in which absence of carbon dioxide reduced phosphate solubility in calcareous soils are of interest. In a study of the nature of the phosphate compounds existing in calcareous soils, it was found that phosphorus is present largely as calcium carbonato-phosphate or carbonato-apatite, a compound formed of three mols tricalcium phosphate and one mol calcium carbonate in which the calcium carbonate is an integral part of the complex molecule. Tricalcium phosphate as such cannot exist under soil conditions. The carbonato-phosphate compound must dissociate in order for the plant to absorb the phosphate ion. Ionization studies showed that dissociation of this compound is greatly reduced by the presence of the common ion calcium.

It is still further reduced by the presence of the solid phase calcium carbonate in presence of calcium ion, and when carbon dioxide is absent from the system the phosphate ion is completely removed from solution. In view of the delicacy of the Deniges method of determining phosphate, complete removal may be interpreted as zero concentration and not 0.1 p.p.m. or even less.

Thus, there can be no ionization of carbonato-phosphate in calcareous soils in the absence of carbon dioxide, and therefore no soluble phosphate, and since this is exactly the condition to be found in badly dispersed soils, the greater fertility of well-aerated or well-drained soils has a sound theoretical basis. A modification of this statement must be allowed for calcareous soils in which exchange sodium is sufficiently high to yield enough free hydroxyl ions to dissolve phosphate and this phase of the problem will be discussed next.

As already mentioned, soils of pH 8.0 to 8.5 usually contain no phosphate in the soil solution. It is self-evident that in this case insolubility is due to the presence of the common ion calcium, the solid

phase calcium carbonate, and deficiency of carbon dioxide. But above pH 8.5 the soil solution is always well supplied with soluble phosphate, yet the crop suffers from phosphate starvation and responds to phosphate fertilization. At first this appeared to be a rather puzzling situation, but a careful study of the problem prompted three quite plausible explanations. These theories embodied the effect of reaction on the ionization of orthophosphates, plant preference for one of the three ions formed by dissociation of orthophosphate, and the effect of reaction on the absorption of phosphate by roots

The ionization of orthophosphoric acid takes place in three steps forming in succession H_2PO_4, HPO_4, and PO_4 ions. There seems to be a common impression among students of plant nutrition that the PO_4 ion is the one absorbed by plants. This will be shown to be untenable if one takes the trouble to calculate, from ionization constants, the concentration of these three ions. Such calculations show that the concentration of PO_4 ion at all reactions is so small that it can be entirely dismissed as playing any direct part in plant nutrition. The ions present in the soil solution are entirely H_2PO_4 and HPO_4. The H_2PO_4 ion is the dominant ion at acid reactions and HPO_4 the dominant ion at alkaline reactions, with both being present in equal proportions at pH 6.8. The reaction of root sap is acid, usually about pH 5.5. The reaction of the root-soil contact film is also acid even in a well-areated calcareous soil, as has been shown, and therefore the dominant ion is the H_2PO_4 ion both in plant sap and in the root-soil contact film. This is probably the only ion which can be absorbed by the plant. In alkaline soils, such as exist in Arizona, HPO_4 is the dominant ion of the soil solution and must be changed to H_2PO_4 previous to absorption by the plant. The ratio of H_2PO_4 to HPO_4 ions will remain substantially constant regardless of concentration and this indicates that greater concentration of phosphate in the soil solution of alkaline soils may be needed to supply the requirements of the crop than would be true for acid soils.

It seems self-evident in the light of our investigations that there is a definite preference or demand on the part of the plant for the H_2PO_4 ion. On the other hand, if one attempts to demonstrate this experimentally another factor in the absorption of phosphate by plants is met. Reference is made to the effect of reaction (pH) on the absorptive processes of the plant and non-absorption of phosphate in the presence of hydroxyl ions. This phase of the problem was quite intensively studied. On growing wheat plants in culture solutions at reactions varying from pH 4.0 to pH 9.0, it was found that there is no absorption of phosphate at reaction pH 9.0, that absorption is measureably reduced at pH 4.0, and is most rapid at reactions just below neutrality. The fact that the HPO_4 ion exists only at alkaline reactions and that plants cannot absorb phosphate in the presence of hydroxyl ions makes it difficult to determine just which exercises the greatest influence upon phosphate starvation in calcareous soils, but it is probable that both are involved.

The means by which the plant overcomes the above obstacles is through the instrument already mentioned, namely, carbon dioxide.

By the exudation of carbon dioxide the alkalinity of the soil solution can be rapidly reduced, the rate depending upon the activity of the roots and this in turn upon the mechanical condition of the soil. The absorption of phosphate in alkaline culture solutions, has been carefully determined at successive time intervals during which the pH was being reduced by the plants and data have been obtained which quite definitely show that there will be no absorption of phosphate by the roots until the reaction (pH) of the root-soil contact zone has been reduced by carbon dioxide exudation to pH 7.6, which is the reaction at which the ratio of H_2PO_4 to HPO_4 ions closely approaches equality.

Briefly summarizing, infertility of alkaline calcareous soils is in large part a nonabsorption of phosphate, and possibly other ions, and less a direct alkaline toxicity. Phosphate availability in such soil types is not a simple matter of solubility, but rather is a complex of several factors to which carbon dioxide is the key. A thorough acquaintance with these factors may be of greater assistance in estimating the phosphate requirement of a soil than a determination of phosphate solubility by means of some empirical reagent.

A COMPARISON OF FIELD METHODS FOR DETERMINING THE AVAILABLE PHOSPHORUS OF SOILS[1]

CLARENCE A. ENGBERG AND CHAS. H. SPURWAY[2]

Considerable progress has been made in recent years in the development of methods for determining the quantities of soluble, or the so-called available[3] phosphorus contained in field soils. Several of these methods have been developed quite recently and a comparison of some of them, using soil samples from unfertilized field plats and plats fertilized with phosphatic fertilizers, is the object of this paper. In the determination of available phosphorus in soils the several workers have used different methods of extracting the phosphorus. In England and some European countries a 1% citric acid solution has been used as the standard extracting solution. In the United States the solutions commonly used for extracting soil phosphorus are 0.2N nitric acid, very dilute sulfuric acid, hydrochloric acid, and water.

Truog (3, 4)[4] has proposed a laboratory method which has been used extensively in Wisconsin for the determination of available phosphorus in soils. A 0.002N sulfuric acid solution buffered to a pH of 3 is used in his method for extracting the soil samples. Truog

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Abstract of a thesis submitted by the senior author to the faculty of Michigan State College in partial fulfillment of the degree of master of science. Published with permission of the Director as Journal Article 115 (n.s.) of the Michigan State Experiment Station. Received for publication October 7, 1932.

[2]Graduate Student in Soils and Research Associate in Soils, respectively.

[3]The term available phosphorus as used in this paper means the quantity of phosphorus determined by the tests used.

[4]Reference by number is to "Literature Cited," p. 360.

has also collaborated with the LaMotte Chemical Company in producing the LaMotte-Truog field tester. Spurway (2) has developed a method of determining the water-soluble phosphorus of the soil and Bray (1) has proposed a somewhat different test for determining the relative quantities of phosphorus in the soil. These four methods have been compared, using the same soil samples, and the results will be discussed in this paper.

PROCEDURE

The soil samples used in this work were obtained from some station experimental plats and cooperative experimental fields located in different parts of the state. Five samples were taken from each plat to a depth of the plowed layer, thoroughly mixed, and a composite sample taken of each lot. All of the samples were then tested in the laboratory using the various tests under the same soil conditions. By following this plan it was possible to study a number of soil types from different parts of the state. The crop yields of these plats were obtained from the records of the fertility work of the Soils Department. The results are presented in Table 1.

DISCUSSION OF EXPERIMENTAL RESULTS

ROSELAWN SANDY LOAM A

Roselawn sandy loam soil is of low fertility in the virgin state. Both Spurway's method and Truog's laboratory method showed that the soil was low in available phosphorus. The LaMotte-Truog method and the Illinois phosphate test showed no deficiency in the available phosphorus of this soil. There was no increase in the yield when phosphatic fertilizers were applied to this soil, except in the case of plat No. 204 which received 600 pounds of superphosphate per acre. When phosphatic fertilizer was applied all of the methods showed an increase in available phosphorus.

ROSELAWN SANDY LOAM B

All of the methods with the exception of the Illinois phosphate test showed that this soil was deficient in available phosphorus. A decided increase in yield was obtained when fertilizer was applied. There was an increasing amount of available phosphorus as the fertilizer applications were increased.

ONAWAY SANDY LOAM A

With the exception of the Illinois phosphate test, all of the methods showed this soil as deficient in available phosphorus. There were no noticeable increases in the yields due to fertilizer additions, however increases were found in the quantity of available phosphorus.

ONAWAY SANDY LOAM B

The LaMotte-Truog method, Truog's laboratory method, and Spurway's method showed that this soil was deficient in available phosphorus. As can be readily seen, there was a good agreement

TABLE 1.—*Available phosphorus by different methods in soils from various experimental fields.*

Plat No.	Treatment	LaMotte-Truog test, lbs. available phosphorus per acre	Spurway's water-soluble phosphorus test, p.p.m.	Illinois phosphate test	Truog laboratory test, p.p.m.	Yield in bushels
		Roselawn Sandy Loam A				
201	No s.p.*	75	0	M†	19.6	221.8
202	200 lbs. s.p.	100	0.5	H	26.2	201.9
203	400 lbs. s.p.	150	1.0	H	50.0	218.1
204	600 lbs. s.p.	150	1.0	H	32.1	234.7
205	800 lbs. s.p.	150	2.0	H	45.5	223.4
		Roselawn Sandy Loam B				
500	Check	75	0.5	H	27.2	37.0
501	375 lbs. 2-16-6	100	1.0	H	30.3	84.1
502	750 lbs. 2-16-6	200	1.0	H	59.5	109.8
503	1500 lbs. 2-16-6	200	2.0	H	69.7	112.2
		Onaway Sandy Loam A				
602	Check	25	0.0	M	13.7	220.4
601	250 lbs. 2-16-6	25	0.5	M	19.4	205.4
603	500 lbs. 2-16-6	75	0.5	H	30.3	221.2
605	1000 lbs. 2-16-6	150	1.0	H	66.5	211.0
		Onaway Sandy Loam B				
201	No s.p.*	50	0.5	H	24.4	179.8
202	200 lbs. s.p.	50	1.0	H	25.8	210.1
208	400 lbs. s.p.	75	1.0	H	36.3	224.9
204	600 lbs. s.p.	75	1.0	H	34.5	225.3
205	800 lbs. s.p.	150	2.0	H	68.5	250.9
		Isabella Sandy Loam A				
601	Check	75	0.0	H	38.8	149.0
602	250 lbs. 2-16-6	100	0.5	H	34.7	142.0
604	500 lbs. 2-16-6	100	0.5	H	39.7	148.3
605	1000 lbs. 2-16-6	150	1.0	H	47.8	166.5
		Isabella Sandy Loam B				
201	No s.p.‡	75	0.0	H	29.2	186.5
202	200 lbs. s.p.	150	0.5	H	41.3	260.1
203	400 lbs. s.p.	150	0.5	H	58.5	282.7
204	600 lbs. s.p.	150	0.5	H	52.3	222.8
205	800 lbs. s.p.	200	1.0	H	68.9	264.9
		Isabella Sandy Loam C				
1	Check	100	0.5	H	40.1	122.0
2	250 lbs. 4-16-8	100	0.5	H	35.1	123.8
3	500 lbs. 4-16-8	150	1.0	H	44.4	118.4
4	750 lbs. 4-16-8	200	2.0	H	23.5	125.3
5	1000 lbs. 4-16-8	200	2.0	H	36.0	137.6
6	1500 lbs. 4-16-8	200	2.0	H	54.0	126.7
7	2000 lbs. 4-16-8	200	3.0	H	72.2	140.1

*s.p. indicates 20% superphosphate. These plats also received 100 lbs. of $NaNO_3$ and 100 lbs. of KCL.
†H is high; M is Medium.
‡These plats also received 67 lbs. of $NaNO_3$ and 133 lbs. of KCL.

TABLE 1.—*Concluded.*

Plat No.	Treatment	LaMotte-Truog test, lbs. available phosphorus per acre	Spurway's water-soluble phosphorus test, p.p.m.	Illinois phosphate test	Truog laboratory test, p.p.m.	Yield in bushels
			Fox Sandy Loam			
1	Check	75	0.5	H†	51.7	171.7
2	250 lbs. 4–16–8	100	1.0	H	48.0	192.9
3	500 lbs. 4–16–8	75	1.0	H	36.9	179.8
4	750 lbs. 4–16–8	150	1.0	H	35.0	207.0
5	1000 lbs. 4–16–8	150	1.0	H	52.6	——
6	1500 lbs. 4–16–8	200	2.0	H	63.2	211.9
7	2000 lbs. 4–16–8	200	2.0	H	51.1	215.4

†H is high; M is medium.

between all the methods, with the exception of the Illinois phosphate test, and the crop response to phosphatic fertilizer. In the case of plats Nos. 208 and 204, to which 400 and 600 pounds of superphosphate were added, respectively, the Truog laboratory method, Spurway's method, and the LaMotte-Truog method showed no increase in the quantity of available phosphorus in plat No. 204 over that of plat No. 208. These results agreed with the crop growth as there was no noticeable increase in the yield. When 800 pounds of superphosphate were added to plat No. 205 there was an increase in the yield with a corresponding increase in the quantity of available phosphorus

ISABELLA SANDY LOAM A

There was sufficient phosphorus in this soil according to the results from the Illinois phosphate test and the LaMotte-Truog test. The results from Spurway's method and Truog's laboratory method indicated that there was a minimum quantity of phosphorus for plant growth present in plats Nos. 601, 602, and 604. When 1,000 pounds of 2–16–6 fertilizer were applied both of the latter methods showed that there was sufficient phosphorus present in the soil. The yield was increased on this plat.

ISABELLA SANDY LOAM B

The results from the Illinois phosphate test indicated that all the plats were high in available phosphorus. The LaMotte-Truog method and Truog's laboratory method indicated that there was a deficiency of available phosphorus in the check plat which received no phosphatic fertilizer. Spurway's method indicated that the available phosphorus content of the soil was low in plats Nos. 201, 202 203, and 204. There was an increase in yield until 600 pounds of superphosphate were added and then there was a decrease in yield. However, when 800 pounds of superphosphate were added, the yield increased over that of the plat which received 600 pounds of superphosphate.

ISABELLA SANDY LOAM C

In this series none of the methods showed a deficiency of available phosphorus and there was no outstanding increase in the yield. Any increase in yield may have been due to the nitrogen or potash of the fertilizer as they were not kept constant.

FOX SANDY LOAM

The results from this series indicated a relation between results from the LaMotte-Truog method and Spurway's method and the crop response to phosphatic fertilizer. This increase in yield may not have been due entirely to the phosphatic fertilizer. As the quantity of fertilizer applied was increased, there was a gradual increase in the quantity of available phosphorus. The Illinois phosphate test was an exception to this as it indicated all of the plats as "high" with the exception of plat No. 7 which was "medium".

In Table 2, a correlation table is shown which gives a comparison between the results obtained with Truog's laboratory method and the other three methods. The comparison between the LaMotte-Truog test and Truog's laboratory method shows that the largest number of soils contained 20 to 30 p.p.m. and the same soils contained 75 pounds per acre of available phosphorus by the La-Motte-Truog method. As the quantity of available phosphorus increased by the Truog laboratory method, the quantity of phosphorus increased by the LaMotte-Truog method. In a comparison of the Illinois phosphate test and Truog's laboratory method, it can be seen that 62 soils contain 10 to 20 p.p.m. of available phosphorus and these same soils are ranked as "high" and "medium" by the Illinois phosphate test. A soil containing only 10 to 20 p.p.m. of available phosphorus would be classed as low in available phosphorus by the Truog laboratory

TABLE 2.—*A correlation table showing the relation between the different methods.*

LaMotte-Truog, pounds per acre	Truog laboratory method, p.p.m. available phosphorus								
	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	Over 80
10	7	1	1	0	0	0	0	0	0
25	1	13	1	0	0	0	0	0	0
50	2	24	8	1	1	0	0	0	0
75	0	29	32	24	3	2	0	1	0
100	0	1	11	19	8	1	0	0	0
200	0	0	1	1	0	3	3	1	0
	Illinois Phosphate Test								
Low	4	0	0	0	0	0	0	0	0
Doubtful	3	4	2	0	2	0	0	1	1
Medium	2	40	16	3	0	0	0	0	0
High	0	22	36	45	22	13	7	3	1
	Spurway's Water-soluble Phosphorus, p.p.m.								
0	6	12	6	9	2	1	0	1	0
0.5	4	51	40	20	9	3	1	1	0
1.0	0	2	9	18	11	7	3	1	2
2.0	0	0	1	1	1	2	3	0	0
3.0	0	0	0	0	0	0	0	1	0

method. In comparison between Truog's laboratory method and Spurway's water-soluble phosphorus method, the largest number of soils were classed as containing 10 to 20 p.p.m. of water-soluble phosphorus. There also were 40 samples containing 20–30 p.p.m. of available phosphorus according to Truog's laboratory method and 0.5 p.p.m. of water-soluble phosphorus. This table would indicate a fair agreement between the Truog laboratory method and Spurway's water-soluble phosphorus method.

SUMMARY

A comparison of four methods for the determination of the available phosphorus of soils was made on soil samples taken from different experiment station fertility plats in Michigan. Three of the methods, *viz.*, Spurway's water-soluble phosphorus method, the Illinois phosphate test, and the LaMotte-Truog method are fundamentally field tests, while the fourth is Truog's laboratory method.

The results from the Illinois phosphate test showed a poor correlation with the crop response of the soils to phosphatic fertilizer treatments. The test showed very little difference between soils deficient in phosphorus and those containing a large amount of available phosphorus as judged from fertilizer applications and crop yields. The Illinois phosphate test as used in this research has shown a tendency to show phosphorus deficient plats as indicated by crop response to phosphatic fertilizer as high in phosphorus. The limiting value of phosphorus in this test in most cases could be established as medium. Very few "low" or "doubtful" soils were found by the use of this method.

The results from the LaMotte-Truog method showed a fair agreement with the crop response to phosphatic fertilizers.

The results from Truog's laboratory method showed a fair correlation to the crop response of the soil to phosphatic fertilizers. However, when large amounts of phosphorus were present in the soil as indicated by the LaMotte-Truog method and fertilizer applications, Truog's laboratory method did not indicate these large amounts. Only one standard is used in this method and that may account for this variation due to the wide difference between the depth of color developed by the standard and the unknown. Because of this wide variation it is not possible to read as accurately when large amounts of phosphorus are present.

The results obtained by Spurway's water-soluble phosphorus method agreed fairly well with the results obtained by the use of phosphatic fertilizers.

The limiting values as established by the LaMotte-Truog method, Spurway's water-soluble phosphorus method, and Truog's laboratory method agree quite well with the results obtained in this study. The LaMotte-Truog method and Spurway's water-soluble phosphorus method could both be recommended as field methods of determining phosphorus deficient soils under Michigan conditions.

Truog's laboratory method could be recommended for use in the laboratory to determine the available phosphorus of soils, although

it is not as rapid as the LaMotte-Truog method and Spurway's water-soluble phosphorus method.

The main difference between all of these methods is in the method of extraction of the phosphorus from the soil, and it is thought a better means of extraction should be developed—one which would show more clearly the true status of the available phosphorus in the soil under different moisture contents and fertilizer treatments.

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NOTES

CIRCULAR REVOLVABLE TRAYS FOR LABORATORY USE

The trays and accessory pedestal here described were devised for use in sugarbeet laboratories, where large numbers of sugarbeet samples were handled in determining their sucrose contents and

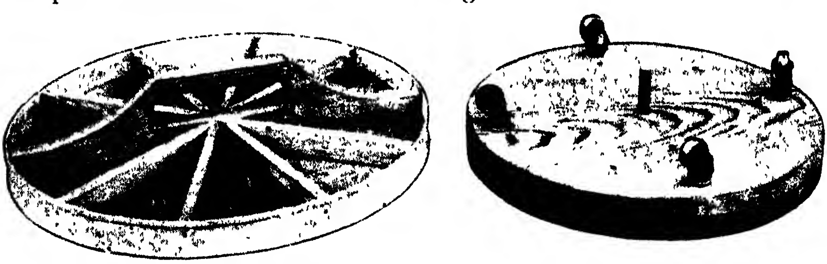

FIG. 1.—A 10-compartment circular tray, 16 inches in diameter, and pedestal and rotating device used for revolving the tray.

coefficients of apparent purity. The identification card, which accompanies the individual samples, can be placed at the side of the container, in the circular tray, with no danger of confusion with other cards. The trays are compact and easily balanced so that a worker can carry two trays holding 10 samples each even in crowded quarters where there is danger of jostling. The device for rotating the trays (Fig. 1) has been found very useful in conveying the containers to a proper position for receiving the fluids measured from the standard pipettes.

The labor-saving features of these trays are important, but the main value is in keeping the samples and identification cards in proper order.

TRAY SPECIFICATIONS

The principle of the circular tray can be adapted to any diameter of tray needed. For pulp containers, trays 18 inches in diameter were

required so as to accommodate the rubber caps commonly used on the monel metal cups. For the filtration of juices where 3½-inch funnels (Fig. 2) were used, it was necessary to make the trays 16 inches in diameter. In handling beakers of raw juice, trays 14 inches in diameter were used. For flasks a smaller and deeper tray with a round compartment division would be more efficient.

The bottom of the tray was made from ½-inch finished pine lumber coated with spar varnish. Several drain holes were bored in the bottom of the tray. These were placed so as not to interfere with the rotation of the tray upon the pedestal. The outer rim of the tray was made from light-weight galvanized iron, with doubled folded top rim, turned out, while the base of the rim had no crimp. These rims extended 1 inch above the bottom of the tray. The handle of the tray was made from 1-inch pine lumber and was only 3 inches high, which permitted stacking of trays when filled with containers. The cross pieces of the tray compartments were made of ½ x 1 inch pine lumber. The handle and cross pieces were treated with spar varnish before assembling. The handle was fastened to the tray bottoms by two screws, and small brads were used in attaching the cross pieces. On the bottom of each tray four small smooth chair glides were driven to aid in sliding the trays on the benches and to raise the tray bottom above any spilled liquids.

FIG. 2.—Circular revolvable tray, partially filled with beakers and funnels, placed upon the pedestal.

PEDESTAL SPECIFICATIONS

The pedestal for these circular trays was made from two circular pieces of 1-inch pine lumber, four small roller chair casters, and a ½-inch iron pin which extended upward about ½ inch higher than the roller casters. The casters were set in an arrangement equidistant from one another each 5 inches from the center pin and at an even height. In the center of the tray bottoms a ¾-inch hole was bored so as to contact with the pedestal pin and hold the trays in position. The pedestals were used only at certain locations in the laboratory, and with a set of 20 trays three or four pedestals were found sufficient. The pedestals were heavy enough to stay in proper position for most operations without being fastened to the benches.—S. B. NUCKOLS, *Division of Sugar Plant Investigations*, and E. S. LYONS, *Division of Soil Fertility, U. S. Dept. of Agriculture, Scottsbluff, Nebr.*

IMPROVEMENT FOR SOYBEAN BAR CYLINDER THRESHER

A soybean bar cylinder thresher, a description of which appeared in this JOURNAL, Volume 21, pages 377–378, has been improved so as to increase its general efficiency. Some of the improvements that have been effected are as follows:

1. The bar cylinder thresher, together with the motor (Fig. 1), has been mounted into a well-built table. The table is of convenient

FIG. 1.—Bar cylinder thresher mounted in a suitably constructed table.

height ($34\frac{1}{2}$ inches) with a good-sized top ($52\frac{3}{4}$ x $37\frac{3}{4}$ inches) suitable for holding one or more bundles of plants.

2. A hole ($15\frac{1}{2}$ x $6\frac{1}{2}$ inches) has been cut in the table top 9 inches from the end and $9\frac{1}{2}$ inches from the side into which the upper part of the thresher fits and through which the plants are fed into the cylinder.

3. A hole is also cut through the 2-inch support for the thresher. The size of the opening is the same as the opening at the lower end of the thresher; and through this opening the seed, chaff, dirt, etc., passes down into the receptacle placed on the floor below.

4. A hood hinged at the back of the opening in the table top serves to prevent the threshed seed from flying out of the cylinder. Of great assistance, too, in keeping the seed from flying unduly is a loose cotton curtain that is attached to the upper part of the front of this hood and hangs down to close the opening through which the plants are fed into the cylinder.

This machine does not have a cleaning device. In practice, it is found that satisfactory separations can be made with the blower-separator, a description of which appeared in this JOURNAL, Volume 24, pages 586–587.

A blue print and specifications will be furnished to any experimentalist upon request.

The writer desires to thank Claude Greenham of the Agronomy Department for designing and building these improvements to the bar cylinder thresher, and M. K. Lyon, mechanical engineering student, for drafting the plans.—G. H. CUTLER, *Department of Agronomy, Purdue University, Lafayette, Indiana.*

BOOK REVIEW

SOIL MANAGEMENT FOR GREENKEEPERS

By M. H. Cubbon and M. J. Markuson. Geneva: The Humphrey Press. 152 pages, illus. 1933. $2.

This book is intended to convey the scientific facts with respect to maintenance of golf grounds. The authors give a clear practical discussion of soils on the basis of their origin. Considerable space is occupied with regard to the relationship of chemical treatment to the maintenance of a favorable reaction. Also the carbon-nitrogen ratio is emphasized to a limited extent.

Slightly less than half of the volume deals with the drainage of golf courses including discussions of different soil types and their requirements.

Numerous tables and definitions of terms are compiled to guide the amateur soil student and others in reading the book.

The following are the chapter titles: The Make-up of Soils, Fundamentals of Chemistry, Plant Nutrients and Soil Acidity, Effects of Organic Matter in Soil, Nitrogen Changes in Soil, General Considerations in Fertilizers, Fertilization of Golf Greens, Fertilization of Fairways, Watering Greens, Use of Weed Killers and Other Poisons, Introduction to Drainage, Engineering Methods, and Profile Leveling.

The volume should serve a definite purpose for the grass culturist and is a departure from the older empirical descriptions. To greenkeepers of golf courses or to caretakers of lawns, it has a real value. (W. S. E.)

AGRONOMIC AFFAIRS

THE SUMMER MEETING OF THE A. A. A. S.

The Society is participating in joint programs with the American Association for the Advancement of Science at the Chicago meetings in June. On Tuesday, June 20, there will be a joint session with Section O, (Agriculture) of the Association, the Botanical Society of America, and Section G, at which Sir Daniel Hall of England and Prof. Ludwig Diels of Berlin will speak. On Wednesday, June 21, joint sessions will be held with the same organizations and the American Society of Phytopathology at which Prof. Jean Dufrenoy of France will be the guest speaker. In the evening of the same day a joint meeting at which Section O will be in charge, Sir Daniel Hall and Prof. Dufrenoy will be the main speakers. On Thursday, June 22, a joint session will be held with the same organizations, the distinguished foreign speaker for this meeting being Prof. Otto Appel of Germany. On Wednesday, June 28, there will be a joint meeting with Section O, Section K, and the Econometric Society on the subject of "Elasticity of Demand for Agricultural Products," with Sir Daniel Hall as the main speaker. The Society will join with the other cooperating organizations in special excursions on the afternoons of Tuesday, Wednesday, and Thursday, June 20, 21, and 22.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 JUNE, 1933 No. 6

THE CALCIUM-MAGNESIUM RATIO IN SOILS AND ITS RELATION TO CROP GROWTH[1]

FRANK MOSER[2]

The calcium-magnesium ratio hypothesis was first proposed by Loew (19)[3]. However, there still exists considerable confusion concerning the significance of the calcium-magnesium ratio as indicated by the bulk analysis of soils. The data recently reported by Bizzell (3) show that of 100 New York soils, 50% contain an excess of magnesium over calcium, an undesirable ratio according to the hypothesis of Loew. However, there is no indication that the yields of the crops on these soils are affected by the excess of magnesium.

The investigation of Loew and May (21) showed that deleterious effects resulted from an excess of magnesia, while an excess of lime produced symptoms of starvation within the plant. They concluded that the best proportion for calcium to magnesium was a molecular ratio of 5:4. The experiments of Loew (20), Furuta (9), Aso (1), Daikaharà (7), Namikawa (32), and Kanomoto (15), indicate that different crops require different ratios, but that there should not be an excess of magnesia, regardless of the kind of crop.

Schreiber (37), Suzuki (38), Bernardi and Siniscalhi (2), Lemmerman, Einecke, and Fischer (17), and Kuffner (25) concluded that the calcium-magnesium ratio is not responsible for the alteration in growth but may influence the solubility of the phosphates. Likewise, Gordon and Lipman (13) showed that the infertility of certain serpentine soils was due to a deficiency of phosphate and nitrate ions rather than to the high proportion of magnesia to calcium.

Gile (10) and Gile and Ageton (11,12) concluded that the toxicity of either an excess of calcium or magnesium cannot be attributed to an unfavorable ratio but may be due either to a physiologically unbalanced solution or to an alteration of soil processes since there

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Condensed from a thesis presented to the Graduate School of Cornell University, September, 1932, in partial fulfillment, for the degree of doctor of philosophy. Received for publication October 11, 1932.

[2]Assistant in Agronomy. The writer wishes to express appreciation to Professor J. A. Bizzell under whose direction this investigation was conducted. Also, to the Department of Soil Technology for providing soil samples and crop records.

[3]Reference by number is to "Literature Cited," p. 375.

are many physical, chemical, and biological factors involved in soil fertility.

Russell (34) found that very little influence was exerted by the calcium-magnesium ratio on soil productivity, as very good and very poor soils were shown to have identical ratios.

Lipman (18) decided from his critical review of numerous papers on the question of lime-magnesia ratios that there was little or no evidence to support belief in the necessity of a proper calcium-magnesium ratio for plant growth. This view is corroborated by the experiments of MacIntire and Shaw (27) and MacIntire and Young (28), who showed that additions of a magnesian or dolomotic limestone to a soil cannot produce a toxic action from an accumulation of magnesium as the outgo of magnesium exceeds that of the calcium and that treating a soil to narrow the calcium-magnesium ratio may result in a decrease of the available potassium.

Meyer (31), Hughes (14), and Pfieffer and Rippel (33) firmly believe that the unsatisfactory yields on soils containing an excess of magnesium were not due to the high magnesia content, but to a deficiency of calcium.

Concerning the ratios of the replaceable calcium to replaceable magnesium in soils, the calcium has invariably been shown to be in excess. Data from Kelley and Brown (16), Catherwood and DeTurk (4), Conrey and Schollenberger (5), Metzer (30), Martin (29), and Wilson (39) show the replaceable calcium-magnesium ratio to be rather variable, ranging from 1:1 to 8:1 for the acid soils.

Crowther and Basu (6) and Schollenberger and Dreibelbis (35) showed that liming increased the replaceable calcium content.

The investigations cited on the question of calcium-magnesium ratios indicate rather definitely that in culture solutions the calcium-magnesium ratio has some bearing on plant growth, while for soils there still remains considerable doubt.

The primary purpose of the present investigation was to determine the relation between the total, the replaceable, and the water-soluble forms of calcium and magnesium of certain soils and to ascertain whether there is any relation between these values and crop growth. Further studies were made upon the same soils to determine whether cropping, liming, or treatment with magnesite produced any modifications.

METHODS OF ANALYSIS

PREPARATION OF SAMPLES

A representative portion of the air-dry soil was placed in a porcelain mortar and disintegrated by means of a rubber-tipped pestle. The soil was then transferred to a sieve that had circular perforations 1 mm in diameter. The portion passing through was used for the analysis.

REPLACEABLE CALCIUM AND MAGNESIUM

The method proposed by Schollenberger and Dreibelbis (36) was used for preparing the neutral normal ammonia acetate solution. The leaching of the soil was accomplished by placing 10 grams of the air-dry soil in a Gooch crucible which had been previously fitted with

a small filter paper and then leached with 250 ml of normal ammonia acetate solution using the apparatus suggested by Fudge (8). The leachate was then transferred to a 250 ml volumetric flask and brought up to volume. An aliquot was used for the calcium determination. Double precipitation with ammonium oxalate was used for the separation and the calcium precipitate was filtered on a Gooch which had been previously prepared with an asbestos pad. After washing with successive increments of hot water, the precipitate was transferred to the beaker and titrated with 0.05 N potassium permanganate.

The magnesium was determined in the combined washings and filtrate. These were acidified with sulfuric acid and evaporated to a small volume. The magnesium was determined by the standard gravimetric method, being weighed as magnesium pyro-phosphate.

The amount of carbonate soluble in the neutral ammonium acetate was determined and the equivalent calcium subtracted from the total dissolved in the ammonium acetate. The difference was assumed to be the amount of replaceable calcium.

HYDROGEN-ION CONCENTRATION

The hydrogen-ion concentration of the soil was determined by making a water suspension of the soil using 25 grams of soil and 50 ml of distilled water. After thorough mixing, 0.2 gram of quinhydrone was added and the pH determined by the potentiometer.

CYLINDER EXPERIMENTS

The cylinder experiments at the Cornell Agricultural Experiment Station offered an excellent opportunity for studying the effects of liming and cropping upon the replaceable calcium and magnesium content. Samples of soil at the beginning and at the end of the experiment were available for study. Records of the crop yields were also available.

The details concerning the cylinder experiments have been previously reported by Lyon (22). Three soil types and eight locations were chosen from the cylinder experiment for the present investigation. They consisted of one Dutchess silt loam from Dutchess County and one from Orange County; one Vergenness clay from Jefferson County and one from Washington County; and one Volusia silt loam from Allegany County, one from Cortland County, and two from Tompkins County.

Certain cylinders of each soil that were limed and unlimed were chosen for the analysis. The limestone had been applied to each soil in accordance with the lime requirement as indicated by the Veitch method. The limestone used in 1916 and in 1920 contained small quantities of magnesium.

CALCIUM AND MAGNESIUM CONTENT AT THE BEGINNING OF THE EXPERIMENT

The total and the replaceable content of calcium and magnesium in the original soils before treatment are shown in Table 1. The

hydrogen-ion concentration for each soil is included. The ratios are expressed in terms of milli-equivalents.

TABLE 1.—*Calcium and magnesium in soils at the beginning of the experiment.*

Soil type and location	Total calcium and magnesium: Per cent air-dry soil		Total calcium and magnesium: Milli-equivalents per 100 grams air-dry soil	Replaceable calcium and magnesium in milli-equivalents per 100 grams air-dry soil			pH
	Ca	Mg	Ca:Mg	Ca	Mg	Ca:Mg	
Dutchess silt loam Dutchess County	0.34	0.44	0.46:1	4.46	1.76	2.63:1	5.25
Dutchess silt loam Orange County	0.23	0.39	0.35:1	1.67	1.63	1.02:1	4.65
Vergenness clay Jefferson County	0.66	1.22	0.33:1	9.87	9.11	1.08:1	6.27
Vergenness clay Washington Co.	0.43	1.40	0.23:1	8.02	6.28	1.28:1	5.72
Volusia silt loam Allegany County	0.35	0.06	2.50:1	5.98	1.89	3.11:1	5.15
Volusia silt loam Cortland County	0.24	0.48	0.30:1	4.21	2.01	2.10:1	5.00
Volusia silt loam Tompkins Co. (Cayuta)	0.52	0.50	0.61:1	8.46	1.84	4.59:1	5.44
Volusia silt loam Tompkins Co. (Turkey Hill)	0.51	0.55	0.45:1	3.00	1.79	1.67:1	4.96

The outstanding feature of these data is that the magnesium is in large excess in six of the eight soils, while one soil, Volusia silt loam from Allegany County, is relatively low in magnesium. Since these soil types are among the most widely distributed in New York State, they present an opportunity to determine the significance of this excess of magnesium represented in a bulk analysis.

Another important feature brought out in this table is that in all cases the replaceable calcium is in excess of the replaceable magnesium. Thus, a comparison between the replaceable and total content of calcium and magnesium of the original soils shows that there is a relatively larger amount of replaceable calcium than of total calcium.

These data show that there is no relation between the total and the replaceable calcium and magnesium. It appears that the amounts of calcium and magnesium in replaceable form are a more logical indicator of the effective physiological balance in the soil solution than is the value shown by a bulk analysis.

REPLACEABLE CALCIUM AND MAGNESIUM AT THE END OF THE EXPERIMENT

The effects of liming and cropping are shown in Table 2. The milli-equivalents given for each soil represent the true replaceable calcium, as correction has been made for the amount of calcium present in carbonate form.

TABLE 2.—*Replaceable calcium and magnesium of soils placed in cylinders at the end of the experiment.*

Soil type	Location	Treatment	Milli-equivalents per 100 grams of air-dry soil			pH
			Ca	Mg	Ca:Mg	
Dutchess silt loam	Dutchess County	Lime	10.36	2.11	4.90:1	7.30
Dutchess silt loam	Dutchess County	No lime	3.57	0.98	3.60:1	5.40
Dutchess silt loam	Orange County	Lime	6.56	1.92	3.40:1	7.00
Dutchess silt loam	Orange County	No lime	0.67	0.72	0.93:1	4.56
Vergenness clay	Jefferson County	Lime	12.78	8.44	1.51:1	7.00
Vergenness clay	Jefferson County	No lime	8.33	8.61	0.97:1	5.95
Vergenness clay	Washington County	Lime	13.15	4.97	2.65:1	6.70
Vergenness clay	Washington County	No lime	7.47	5.62	1.33:1	5.65
Volusia silt loam	Allegany County	Lime	14.21	2.05	7.00:1	6.75
Volusia silt loam	Allegany County	No lime	4.16	1.21	3.42:1	4.90
Volusia silt loam	Cortland County	Lime	13.28	2.67	5.00:1	6.80
Volusia silt loam	Cortland County	No lime	2.91	1.83	1.59:1	4.60
Volusia silt loam	Tompkins County (Cayuta)	Lime	11.23	2.69	4.13:1	7.15
Volusia silt loam	Tompkins County (Cayuta)	No lime	6.70	1.74	3.85:1	5.20
Volusia silt loam	Tompkins County (Turkey Hill)	Lime	8.37	1.96	4.26:1	6.80
Volusia silt loam	Tompkins County (Turkey Hill)	No lime	1.79	1.42	1.26:1	4.63

Liming increased decidedly the amount of replaceable calcium in every soil, while there was a slight increase in replaceable magnesium. The calcium-magnesium ratio has widened in all of the soils. The lime was variable in its effects upon the individual soils. Although lime increased the replaceable calcium in all soils, the increase was larger in some cases than in others. This can be attributed to a difference in the colloidal complex of each soil.

The effects of cropping upon the replaceable calcium and magnesium content are shown by the unlimed cylinders. Cropping reduced the milli-equivalents of calcium and magnesium during the experiment. However, this reduction did not always result in a lower calcium-magnesium ratio, which was due to differences in the replacement of these two constituents. Magnesium seems to be held more tightly and as a result the calcium was exchanged for hydrogen much

more rapidly than the magnesium. Thus, the influence of continuous cropping tends to deplete the soil of replaceable constituents and as a result the calcium-magnesium ratio approaches unity.

THE INFLUENCE OF MAGNESITE UPON REPLACEABLE CALCIUM AND MAGNESIUM

Since the plan of the cylinder experiment did not provide for a treatment with pure magnesium salt, a laboratory experiment was set up in order to supplement the cylinder experiment to show the effect

TABLE 3.—*The effect of magnesite on replaceable calcium and magnesium.*

Soil type and treatment	Location	Milli-equivalents per 100 grams of air-dry soil			pH
		Ca	Mg	Ca:Mg	
Dutchess silt loam	Dutchess County				
1 ton of magnesite		4.46	4.60	0.98:1	6.50
2 tons of magnesite		4.46	5.71	0.78:1	6.93
Dutchess silt loam	Orange County				
1 ton of magnesite		1.78	6.02	0.29:1	6.45
2 tons of magnesite		1.78	7.41	0.24:1	6.80
Vergenness clay	Jefferson County				
1 ton of magnesite		9.67	11.95	0.81:1	6.80
2 tons of magnesite		9.81	12.76	0.76:1	7.01
Vergenness clay	Washington County				
1 ton of magnesite		8.77	9.18	0.95:1	6.60
2 tons of magnesite		8.92	11.22	0.80:1	7.05
Volusia silt loam	Allegany County				
1 ton of magnesite		4.00	5.39	0.74:1	5.60
2 tons of magnesite		4.01	7.83	0.51:1	6.10
Volusia silt loam	Cortland County				
1 ton of magnesite		4.76	6.01	0.78:1	6.30
2 tons of magnesite		4.91	8.72	0.56:1	7.20
Volusia silt loam	Tompkins County (Cayuta)				
1 ton of magnesite		8.92	6.10	1.46:1	5.50
2 tons of magnesite		9.06	8.80	1.03:1	6.40
Volusia silt loam	Tompkins County (Turkey Hill)				
1 ton of magnesite		3.27	4.94	0.66:1	5.20
2 tons of magnesite		3.57	7.60	0.47:1	5.70

of pure magnesite upon the replaceable calcium and magnesium. For this experiment, 2,000 grams of each of the original soils used in the cylinder experiment were passed through a 1-mm sieve and then mixed thoroughly with a definite amount of magnesite corresponding to applications of 1 and 2 tons per acre. The soils were placed in half-gallon mason jars and kept at 20% moisture content for a period of 130 days after which they were air dried, sieved, and analyzed.

The influence of magnesite upon the replaceable calcium and magnesium is shown in Table 3. These results show conclusively

that magnesium carbonate has very little, if any, effect upon the replaceable calcium as the amounts of replaceable calcium were approximately the same regardless of the quantity of magnesite added. The amount of exchangeable calcium was not appreciably different from that present originally.

The carbonate analysis showed that the excess magnesite was not present in the soil as a carbonate. This confirms the view of MacIntire, Willis, and Hardy (26) that magnesium carbonate does not persist in a humid region soil, but is converted over to a silicate form within a relatively short time.

These results indicate rather definitely that in order to increase the replaceable magnesium in any soil, a magnesium compound must be added. Likewise, an increase in replaceable calcium may be accomplished by additions of a calcium salt. Further, this experiment explains the increase of replaceable magnesium of the cylinder soils as sufficient magnesium carbonate was present as an impurity in the limestone.

CALCIUM AND MAGNESIUM RATIOS AND CROP YIELDS

In the cylinder experiment previously described, crops were grown each year. The cropping system consisted of a rotation of barley, red clover, fodder corn, and timothy. Complete records were kept during the entire time of the experiment. These have been reported by Lyon (22) and are summarized in Table 4. The yield data show that liming gave large increases in some soils, while in others there was little or no effect.

A comparison between Tables 1 and 4 shows that there is no apparent relation between the total calcium-magnesium ratios shown by a bulk analysis and the response to liming. This is conclusively shown by the crop yields produced on the Vergenness clay from Washington County. The calcium-magnesium ratio is 0.23:1, an undesirable ratio according to the hypothesis of Loew. However, an application of lime on this soil gave only a 15% increase and only a 5% increase when lime was applied with complete fertilizer. These increases are small and are considered insignificant. In the case of the Volusia silt loam from Allegany County, the ratio is 2.50:1, which would indicate that lime was not necessary, but a significant increase of 109% was obtained with lime regardless of the favorable ratio.

The Dutchess silt loam from Orange County and the Vergenness clay from Jefferson County have approximately the same ratio, but lime applied to these two soils responded differently. A slight decrease occurred on the Jefferson County soil, while a 400% increase was obtained from the Orange County soil. Thus, it appears that the ratio of total calcium to total magnesium in these soils has no significant bearing on crop growth.

A comparison of the replaceable calcium-magnesium ratio and crop yields can be obtained from Tables 1 and 4. The replaceable calcium-magnesium ratio of the Dutchess silt loam from Orange County and the Vergenness clay from Jefferson County have identical ratios, 1:1, and should be desirable for maximum growth. The yield data show that liming has increased the yield 400% on the Orange

County soil, while it decreased the yield 2% on the Jefferson County soil. A further comparison between the Vergenness clay soils and all the other soils of this investigation shows a significant increase for liming obtained for all the others regardless of the calcium-magnesium ratio.

TABLE 4.—*Average annual yields of all crops in cylinder experiments.*

Soil type and location	Actual yield in grams				Relative yields			
	No lime, no fertilizer	Lime, no fertilizer	NPK, no lime	NPK, lime	No lime, no fertilizer	Lime, no fertilizer	NPK, no lime	NPK, lime
Dutchess silt loam. . Dutchess County	52	108	152	232	100	208	100	152
Dutchess silt loam. . . Orange County	22	110	72	212	100	500	100	294
Vergenness clay . Jefferson County	146	143	220	233	100	98	100	106
Vergenness clay. . . Washington Co.	116	134	218	231	100	115	100	105
Volusia silt loam . Allegany County	82	172	143	232	100	209	100	162
Volusia silt loam . . Cortland County	55	167	186	225	100	303	100	121
Volusia silt loam . Tompkins County (Cayuta)	62	132	161	240	100	212	100	149
Volusia silt loam Tompkins County (Turkey Hill)	14	96	71	203	100	685	100	286

The data show that the replaceable calcium-magnesium ratio has no significance in these soils on crop growth. However, the determining factor for crop production appears to be the amount of replaceable calcium and the beneficial effects of liming are not due to a change in the ratio of calcium to magnesium, but to the increase in the amount of the replaceable calcium. This is brought out more conclusively by comparing the amount of replaceable calcium in the original soils and the amount after liming. The original soils that were high in replaceable calcium gave little or no response to lime, while soils that were low at the outset gained in replaceable calcium and consequently produced a higher yield.

LYSIMETER EXPERIMENTS

The lysimeter experiments at Cornell University Agricultural Experiment Station offered further opportunity to study the calcium-

magnesium ratios of soils. A complete description of the construction of the lysimeters has been previously given by Lyon and Bizzell (23).

The soil was placed in the tanks in the summer of 1909 and subjected to a rotation of maize, oats, wheat, timothy, etc. The tanks selected for study were Nos. 3, 5, and 6 of the unlimed series and Nos. 8, 9, and 10 of the limed series. All tanks received the same fertilizer treatment, but tanks 8, 9, and 10 received applications of burned lime in 1910, 1915, 1920, and 1922 at the rate of 3,000 pounds per acre. The burned lime was calcium oxide with only minute traces of magnesium oxide.

CALCIUM AND MAGNESIUM CONTENT AT THE BEGINNING OF THE EXPERIMENT

Analyses of the original soil used in the lysimeter experiment, as given by Lyon, *et al.* (24), show the percentage of calcium and magnesium to be 0.34 and 0.35%, respectively. The total calcium-magnesium ratio is 0.59:1.

The tanks were all filled with the same soil type, Dunkirk silty clay loam. The replaceable calcium and magnesium content of this soil was 2.99 milli-equivalents of calcium and 2.27 milli-equivalents of magnesium. The replaceable calcium-magnesium ratio was 1.31:1. These data show that for replaceable constituents the calcium is in excess, while the bulk analyses show that there is relatively more magnesium; also, that there seems to be no relation between the amount of replaceable content of calcium and magnesium and the total amount.

WATER-SOLUBLE CALCIUM AND MAGNESIUM IN THE DRAINAGE WATER

The drainage water from the lysimeters shows that the ratio of water-soluble calcium to magnesium is rather constant and fluctuates slightly from 3.00 to 4.15. The data for the water-soluble ratios are shown in Table 5.

TABLE 5.—*Water-soluble calcium and magnesium in drainage water.*

Treatment	Cropping system	Milli-equivalents per 100 grams of air-dry soil		
		Ca	Mg	Ca:Mg
No lime	Cropped	0.282	0.068	4.00:1
Limed	Cropped	0.300	0.098	3.00:1
No lime	Bare	0.356	0.085	4.15:1
Limed	Bare	0.391	0.110	3.55:1

The important feature of these data is that there is a large excess of calcium over magnesium. The ratio remains fairly constant regardless of cropping, fallowing, or liming. However, liming has a tendency to narrow the ratio of water-soluble calcium to magnesium. This is due primarily to an increased solubility of magnesium in the drainage, while the calcium has been increased slightly. Cropping has maintained a narrow ratio, while fallowing has slightly widened this ratio.

REPLACEABLE CALCIUM AND MAGNESIUM AT THE END OF THE EXPERIMENT

The effects of liming, cropping, and fallowing are shown in Table 6. The data show that the ratio of the replaceable calcium to magnesium has been increased regardless of treatment. The unlimed tanks have approximately the same ratios, while the limed tanks have much wider ratios than at the outset of the experiment. This can be attributed to the fact that lime has increased the loss of magnesium in the drainage water and has increased the replaceable calcium content of the soil.

TABLE 6.—*Replaceable calcium and magnesium at the end of the experiment.*

Tank No.	Treatment	Cropping system	Milli-equivalents per 100 grams of air-dry soil			pH
			Ca	Mg	Ca·Mg	
4	Manure, no lime	Bare 10 yrs., cropped 5 yrs.	2.23	1.44	1.55:1	5.10
8	Manure, lime	Bare 10 yrs., cropped 5 yrs.	6.42	1 79	3 58:1	6.70
5	Manure, no lime	Cropped 15 years	2.70	1.79	1.50:1	4.90
9	Manure, lime	Cropped 15 years	8.55	2.13	4.00:1	6.90
6	Manure, no lime	Cropped 10 yrs., bare 5 yrs.	2.38	1 71	1.39.1	5.10
10	Manure, lime	Cropped 10 yrs , bare 5 yrs.	7.87	2.07	3 80:1	6.70

In contrasting the treatments of tanks 4, 5, and 6, a greater loss of both calcium and magnesium occurred on the bare soil than on the cropped soil. This was expected, as the data presented by Lyon, *et al.* (24), clearly showed that the bare soil lost more calcium and magnesium by leaching than the combined losses from leaching and the crop of the planted tank. Thus, with a loss of both of these constituents, a similar ratio would be expected. However, it appears that the magnesium was lost more rapidly than the calcium which resulted in a slightly higher ratio than the original soil of the cropped tank. Likewise, tank 6, which remained in grass the first 10 years and bare the remaining 5 years, lost more of its exchangeable constituents than the cropped tanks but had a lower calcium-magnesium ratio than either tank 4 or 5, while the ratio remained approximately the same as the original soil.

Likewise, this diminution of the replaceable calcium and magnesium was noticeable between the bare and cropped tanks in the limed series. The lowering of the amount of magnesium was rather striking in the bare tank, while the cropped tank retained approximately the same amount of replaceable magnesium. This effect was confirmed to some extent by tank 5 which was bare only 5 years. As a consequence, the amount of exchangeable magnesium was lowered by the addition of lime. This effect was more noticeable on the bare

tanks than on the cropped, and as a result the calcium-magnesium ratios were somewhat lower.

The data from the lysimeter soils show that liming caused an increase in the replaceable calcium content and caused an increase of the calcium-magnesium ratio over that of the original soil. However, these data differ somewhat from those obtained in the cylinder experiment with respect to the effect of lime upon the replaceable magnesium content. The addition of lime in the cylinder experiment had a tendency to increase slightly the replaceable magnesium content, while there was no noticeable increase in the lysimeter experiment. This difference is due to the lime material added to each experiment. The burned lime added to the lysimeter soils was calcium oxide with only minute traces of magnesium, while the limestone added to the cylinder soils had approximately 2% magnesium carbonate. Thus, by adding some magnesium in the latter case, one would expect an increase in replaceable magnesium.

SUMMARY

The study of soils from the cylinder experiment shows that there were wide differences between the total and the replaceable content of calcium and magnesium and that the total amount of calcium and magnesium had no influence upon the amount held in replaceable form.

The calcium-magnesium ratio, based on milli-equivalents, of these soils varied from 0.23:1 to 2.50 1 when based on total content, but the ratios were from 1:1 to 4.50:1 when based on the replaceable amount.

No significant correlation was found between the calcium-magnesium ratio and crop yields, but the significant factor in determining yields was the amount of active calcium in a soil.

The beneficial effect of adding lime to a soil was not due to an alteration of the calcium-magnesium ratio, but to an increase of the replaceable calcium content of a soil.

The increase of the replaceable cation content of any soil seemed to be determined largely by the type of carbonate added. Pure magnesite markedly increased the replaceable magnesium content with no appreciable effect on replaceable calcium, while pure calcium carbonate increased only the replaceable calcium content. However, the limestone added in the cylinder experiment increased slightly the replaceable magnesium, but some magnesium was accidently carried as an impurity of the limestone.

The study of the lysimeter soils gave results similar to those obtained in the cylinder experiment, namely, there was no correlation between the total, the replaceable, and the water-soluble calcium and magnesium of a soil.

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THE RATES OF REACTION WITH ACID SOILS OF FINELY DIVIDED SOIL LIMING MATERIALS[1]

W. H. METZGER[2]

In attempting to measure the agricultural value of a by-product precipitated carbonate of lime produced in the manufacture of soda ash, the question arose as to whether any practical difference exists in the rate at which finely divided burned and carbonate forms of lime react with acid soils. Interest centered particularly in four classes of materials sold commercially for liming soils in Ohio, i.e., hydrated lime, a precipitated carbonate of lime sold under the trade name of "Plant Lime", finely pulverized high calcium limestone, and finely pulverized dolomitic limestone. While it is generally recognized that all of these materials possess relatively high efficiency, not infrequently claims for superiority have been made for hydrated lime over the carbonate forms, for precipitated carbonate over the natural carbonates, and for high calcium over dolomitic pulverized limestones.

In a laboratory study, Morgan and Salter (5)[3], employing 40- to 50-mesh and 80- to 100-mesh separates of 10 limestones of diverse origin, one marble sample and one natural precipitated carbonate (travertine), could find no relation between the rates of dissolution, in either buffered acid or acid soil, and such physical properties as

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Part of a thesis presented to the Graduate School of the Ohio State University in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication October 18, 1932.

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[3]Reference by number is to "Literature Cited," p. 383.

hardness, porosity, structure, or color. However, rate of reaction appeared to be negatively correlated with the percentage of magnesium contained. It is notable that with the three most active limestones applied at the rate of 10 tons per 2,000,000 pounds of soil to an acid DeKalb sandy loam dissolution approximated 65% for the 100-mesh and 54% for the 50-mesh separate during a 20-day incubation period.

Dorsey (2), using lime requirement, pH, and residual carbonates as criteria, found hydrated lime more rapid in its action than ground limestone, even when the latter was ground to such fineness that 81% passed a 0.1-mm screen (about 150 mesh). Soils incubated with ground limestone showed a progressive reduction in acidity for about 6 weeks, then frequently an increase during the final 2 weeks. In soil treated with hydrated lime this increase occurred after the third week.

Walker, Brown, and Young (7) found 100-mesh limestone about equal in effectiveness to hydrated lime in reducing the hydrogen-ion concentration of soil. Dolomitic limestone was equally as effective as high calcium stone. The soil showed a higher lime requirement 6 months after treatment with lime than it did 3 months after such treatment.

Numerous workers have reported dolomitic limestones to be slower than high calcium stones in their reaction with acid soils, the difference becoming smaller as the fineness of grinding is increased.

MATERIALS AND METHODS

The rates of reaction with acid soils were determined in a laboratory study for the following materials: (a) A high calcium pulverized limestone, (b) a dolomitic pulverized limestone, (c) a high calcium hydrated lime, and (d) a precipitated carbonate designated commercially as "Plant Lime". The latter contained about 5% of sodium and calcium chlorides. The screen analyses and total neutralizing powers of these materials are presented in Table 1. Each material was added at three rates to 200-gram portions of each of two soils, a Canfield silt loam (pH 5.00; Jones lime requirement 4,096 pounds) and a Mahoning silty clay loam (pH 4.55; Jones lime requirement 5,344 pounds). The heaviest application on each soil was well below the indicated lime requirement of the soil.

Sufficient cultures were made up to provide for taking down triplicates of each treatment after incubation periods of 1 and 2 weeks and 1, 2, 6, and 12 months. The soils were brought to approximately optimum moisture content and incubated at 30°C in a practically saturated atmosphere. After taking down, the soils were dried, first at 60° C and finally at 105° C for 1 hour. The rate of reaction was measured by three criteria, *viz.*, pH by the quinhydrone electrode procedure, lime requirement essentially by Baver's (1) modification of the Jones (3) method, and residual carbonates determined by the method of Schollenberger (6). Carbonates were not determined in the cultures incubated 12 months.

TABLE 1.—*Fineness and total neutralizing power of liming materials employed.*

Separate	Pulverized high calcium limestone %	Pulverized dolomitic limestone %	"Plant Lime" %	Hydrated lime* %
Coarser than 10-mesh	0.06	0.00	0.00	———
10- to 20-mesh	1.08	3.58	0.08	———
20- to 40-mesh	3.14	6.55	0.25	———
40- to 50-mesh	3.86	3.60	0.94	———
50- to 60-mesh	2.26	1.91	1.24	———
60- to 80-mesh	7.24	7.28	4.45	———
80- to 100-mesh	0.83	1.01	0.63	———
100- to 150-mesh	14.69	20.60	16.90	———
150- to 200-mesh	27.35	17.47	22.54	———
Finer than 200-mesh	39.49	38.00	52.97	———
Total neutralizing power†	95.00	105.00	92.50	123.00

*Fineness was not determined for the hydrated lime, since the fineness of lime in this form is never called in question.

†$CaCO_3$-equivalent.

DISCUSSION OF RESULTS

The pH determinations proved unsatisfactory for measuring the rates of reaction. The pH of the unlimed check cultures decreased progressively throughout the 12-month period, the total change amounting to 0.78 pH for the Canfield and 0.53 pH for the Mahoning soil. The changes in pH produced by the lime treatments, although varying in accordance with the rates of application, were small and in general no larger after 12 month's incubation than after 1 week, even with the least active material, accordingly the data will not be presented

In Tables 2 and 3 are shown the rates of application employed for the Canfield and Mahoning soils, respectively, and the corresponding percentage decomposition of the added lime for each period up to 6 months as determined from the residual carbonate measurements. Such use of the latter data in the case of hydrated lime assumes complete carbonation. Since the conditions of incubation employed favored rapid production of CO_2 and in view of MacIntire's (4) findings that "maximum carbonation of 2 tons CaO and $Ca(OH)_2$ applications occurred within 5 days after mixing with the soil," it is believed that the hydrated lime was probably completely carbonated before the first sampling date.

The $CaCO_3$-equivalents of the lime decomposed, stated in pounds per 2 millions of soil, for the variosu cultures are compared with the corresponding decreases in Jones lime requirement in Tables 4 and 5.

It is evident from the carbonate data that both "Plant Lime" (precipitated carbonate) and hydrated lime reacted more rapidly than the natural carbonates and also that the high calcium limestone dissolved more rapidly than the dolomitic stone. If any difference exists in the rates of reaction of the precipitated carbonate and hydrated lime, it is so small as to be masked by the experimental errors involved. The precipitated carbonate dissolved more rapidly

TABLE 2.—*Rates of decomposition of four forms of lime in Canfield silt loam soil.*

Application in lbs. $CaCO_3$-equivalent per 2,000,000 lbs. soil	Percentage $CaCO_3$ decomposed in samples incubated for				
	1 week	2 weeks	1 month	2 months	6 months
			Pulverized High Calcium Limestone		
500	91.8	93.6	58.0	90.0	98.4
1,000	77.6	76.8	75.8	93.4	92.6
2,000	73.5	72.5	80.4	85.0	91.3
			Pulverized Dolomitic Limestone		
500	75.6	73.6	78.0	97.2	91.6
1,000	39.6	39.2	62.4	90.0	95.0
2,000	40.2	63.8	63.7	84.2	92.5
			"Plant Lime"		
500	100.0	95.0	94.8	98.4	98.4
1,000	92.4	96.8	75.8	100.0	99.2
2,000	81.8	82.5	87.9	97.9	97.5
			Hydrated Lime		
500	89.2	100.0	88.4	96.8	100.0
1,000	90.0	100.0	90.8	100.0	99.2
2,000	81.9	95.9	92.9	99.2	96.7

TABLE 3.—*Rates of decomposition of four forms of lime in Mahoning silty clay loam soil.*

Application in lbs. $CaCO_3$-equivalent per 2,000,000 lbs. soil	Percentage of $CaCO_3$ decomposed in samples incubated for				
	1 week	2 weeks	1 month	2 months	6 months
			Pulverized High Calcium Limestone		
1,000	65.8	92.0	93.2	91.0	93.6
2,000	74.6	87.1	89.1	90.8	95.6
4,000	72.7	83.4	87.5	89.2	92.2
			Pulverized Dolomitic Limestone		
1,000	44.2	63.6	93.2	88.4	95.2
2,000	56.3	62.5	83.7	89.2	92.1
4,000	57.9	73.0	75.0	84.4	89.1
			"Plant Lime"		
1,000	81.8	93.6	99.2	96.6	98.6
2,000	84.2	90.1	97.1	97.5	98.5
4,000	84.8	93.6	96.2	95.2	98.4
			Hydrated Lime		
1,000	89.2	99.4	93.2	95.0	98.6
2,000	83.8	80.3	98.7	92.5	99.3
4,000	88.0	89.3	97.5	92.5	98.0

than the high calcium limestone. The difference in carbonate loss between the two materials, averaging the data for all three rates of application, amounts to 10.4 and 10.5%, respectively, for the 1- and 2-week periods with the Canfield soil and to 12.6 and 4.9% for the

TABLE 4.—*Comparison of the decrease in Jones lime requirement and the decomposition of $CaCO_3$ in Canfield silt loam.*

Application in lbs. $CaCO_3$-equiv. per 2,000,000 lbs. soil	Decreases of lime requirement and carbonates in lbs. $CaCO_3$ per 2,000,000 lbs. soil in									
	1 week		2 weeks		1 month		2 months		6 months	
	L.R.	$CaCO_3$	L.R.	$CaCO_3$	L.R.	$CaCO_3$	L.R.	$CaCO_3$	L.R.	$CaCO_3$
					Pulverized High Calcium Limestone					
500...	683	454	128	468	21	290	279	450	170	492
1,000...	976	776	391	768	213	757	469	934	362	926
2,000...	1,333	1,470	1,237	1,450	747	1,608	932	1,700	789	1,826
					Pulverized Dolomitic Limestone					
500...	416	378	64	368	17	390	0	476	170	458
1,000...	800	396	106	392	363	624	555	900	362	950
2,000...	907	904	960	1,276	555	1,274	640	1,684	768	1,850
					"Plant Lime"					
500.....	758	500	181	450	213	474	427	492	277	492
1,000...	992	924	490	968	363	758	576	1,000	362	992
2,000...	1,632	1,636	1,549	1,650	640	1,758	896	1,958	864	1,950
					Hydrated Lime					
500.	715	446	128	500	85	442	268	484	170	500
1,000...	992	900	672	1,000	299	908	427	1,000	426	992
2,000.	1,205	1,638	1,322	1,918	789	1,918	875	1,984	810	1,934

TABLE 5.—*Comparison of the decrease in Jones lime requirement and the decomposition of $CaCO_3$ in Mahoning silty clay loam.*

Application in lbs. $CaCO_3$-equiv. per 2,000,000 lbs. soil	Decreases of lime requirement and carbonates in lbs. $CaCO_3$ per 2,000,000 lbs. soil in									
	1 week		2 weeks		1 month		2 months		6 months	
	L.R.	$CaCO_3$	L.R.	$CaCO_3$	L.R.	$CaCO_3$	L.R.	$CaCO_3$	L.R.	$CaCO_3$
					Pulverized High Calcium Limestone					
1,000.....	128	658	832	920	640	932	192	908	512	936
2,000.....	1,280	1,492	1,536	1,752	960	1,782	939	1,816	960	1,912
4,000.....	1,739	2,908	2,432	3,340	1,472	3,500	2,048	3,566	2,240	3,686
					Pulverized Dolomitic Limestone					
1,000.....	213	442	725	636	661	932	555	884	405	952
2,000.....	693	1,126	1,154	1,260	1,045	1,674	811	1,784	853	1,842
4,000.....	1,387	2,234	1,685	2,928	1,728	3,000	1,579	3,376	1,621	3,562
					"Plant Lime"					
1,000.....	203	818	512	936	512	992	704	966	256	986
2,000.....	1,109	1,684	1,152	1,802	1,067	1,942	1,024	1,950	853	1,970
4,000.....	1,792	3,392	2,432	3,744	2,261	3,850	1,963	3,808	1,984	3,936
					Hydrated Lime					
1,000.....	117	892	704	994	832	932	384	950	512	986
2,000.....	1,131	1,676	1,131	1,686	1,216	1,974	1,131	1,850	1,024	1,986
4,000.....	2,176	3,518	2,261	3,570	2,432	3,900	2,219	3,700	1,877	3,920

same periods with the Mahoning soil. It is believed that the difference is largely accounted for by the 10.9% higher content of material finer than 100 mesh in the precipitated carbonate.

A similar comparison between the high calcium and dolomitic limestones shows the former to be measurably more rapid in its action. The difference in carbonate loss averages 29.2 and 22.1%, respectively, for the 1- and 2- week periods with the Canfield soil and 18.3 and 21.1% with the Mahoning soil. Although the high calcium stone was slightly finer, containing 5.5% more 100-mesh material, it seems probable that most of the difference in dissolution rate is attributable to a slower specific solubility of the high magnesium stone. It is notable, however, that the difference between the two stones had largely disappeared after 2 months incubation. Although dissolution under field conditions would doubtless be somewhat slower, it seems unlikely with materials of such fineness that the slower initial reaction of dolomitic limestones has much practical significance.

It is of interest to compare the rates of reaction as indicated by the three criteria carbonate loss, reduction in lime requirement, and pH change. The data for carbonate loss show clearly that progressive dissolution with increasing time took place with all materials. This is most notable with the less active dolomitic limestone. On the other hand, lime requirement reached an early minimum followed by a material increase. It has already been noted that the increases in pH over the check soils did not change sensibly after the first week with any of the treatments. While the author is unable to offer any adequate explanation for these relationships, it is believed that they point to the undesirability of employing change in pH or Jones lime requirement for measuring the rates at which liming materials react with incubated soils.[4]

SUMMARY

The study reported pertains to the reaction rates of four finely divided liming materials with two acid soils. The materials included were hydrated lime, pulverized high calcium limestone, pulverized dolomitic limestone, and a by-product precipitated calcium carbonate known commercially as "Plant Lime". All materials were employed at three rates of application and in chemically equivalent amounts. Change in pH, decrease in Jones lime requirement, and decrease in total carbonates were used as criteria of rate of reaction. The incubation periods varied from 1 week to 1 year.

Both pH change and decrease in lime requirement proved unreliable indicators of rate of reaction. The former remained approximately constant after 1 week. Lime requirement reached a minimum in 1 or 2 weeks and thereafter showed a material increase.

Based upon the disappearance of carbonates, hydrated lime and the precipitated carbonate were about equally rapid in reaction. The precipitated carbonate reacted faster than the high calcium

[4]The author made some study of the behavior of the Jones lime requirement with progressive decrease in soil acidity. The results will be presented in a later paper.

limestone. The difference can probably be accounted for by the somewhat greater fineness of the former. The dolomitic limestone was measurably less active than the high calcium limestone, the difference largely disappearing after 2 months incubation.

It is doubtful whether any practical significance may be attributed to the differences in rates of reaction among the materials studied.

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A COMPARISON OF VARIOUS METHODS FOR DETERMINING THE FERTILIZER NEEDS OF CERTAIN SOILS[1]

F. B. SMITH, P. E. BROWN, AND O. R. NEAL[2]

Many soils are deficient in one or more of the essential plant food elements, and for maximum crop yields these elements must be added. Commercial fertilizers varying widely in composition are available for supplying the elements of plant food most likely to be deficient in soils and the choice of the material to be used depends upon the needs of the particular soil. In order to secure the greatest economic returns from the application of a fertilizer, the needs of the soil should be determined accurately to ascertain the kind and amount of fertilizer which should be used.

A number of biological and chemical tests and also greenhouse and field tests have been proposed for determining the fertilizer needs of soils. The purpose of this investigation was to study several of these methods and to compare the results secured from their use on Carrington loam, an important Iowa soil.

HISTORICAL

Dyer (5)[3] reviewed the literature previous to 1894 on the determination of available plant food constituents in the soil. He found

[1]Contribution from the Department of Farm Crops and Soils, Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper No. B 76. Received for publication October 20, 1932.

[2]Research Associate, Head of Department, and Fellow, respectively.

[3]Reference by number is to "Literature Cited," p. 391.

that investigators up to that time regarded phosphates soluble in dilute hydrochloric acid or dilute acetic acid or ammonium citrate as available and that soils containing phosphates removable by these solvents as a general rule were not benefited by applications of phosphate fertilizers. Dyer found that a 1% citric acid solution indicated fairly well the available phosphates in soils; undoubtedly because it approximated the average strength of the root sap, the natural solvent. He suggested that a soil needs a phosphate fertilizer when it contains as little as 0.01% P_2O_5 soluble in 1% citric acid.

Russell and Prescott (13) found little difference in the solvent action of equivalent concentrations of nitric, hydrochloric, and citric acids, but sulfuric acid removed larger amounts of phosphoric acid.

Shedd (15) stated that soils, to be productive, should show at least 0.005% of the total phosphorus soluble in 0.2 N nitric acid.

Atkins (2), Parker and Fudge (11), Truog and Meyer (19), Bray (3), Spurway (16), and Truog (18) have developed methods for determining the amounts of soil phosphates soluble in water or dilute acids.

Neubauer and Schneider (9) described a method for determining the plant food deficiencies in soils which is based upon the assumption that a large number of plants growing on a relatively small amount of soil will very quickly extract all of the readily available plant food constituents from the soil. The amounts removed are determined by analysis of the plant material. The minimum amounts of phosphoric acid and potash which should be available for good crop production in 100 grams of soil are given.

The Neubauer method has been employed by Roemer (12), Ames and Gerdel (1), Densch (4), Harris (6), and Thornton (17). While satisfactory results have been secured by some investigators, it is generally accepted that the method does not give results which correspond to field tests.

Niklas, Poschenrieder, and Trischler (10) found a close correlation between the amount of growth made by *Aspergillus niger* on a given soil and the amount of phosphate assimilated from the same soil in the Neubauer test. They concluded that the amount of growth made by this mold was proportional to the amount of available phosphorus in the soil and they outlined a method for the determination of the phosphorus needs of the soil based on the growth of *A. niger*.

Sackett and Stewart (14) secured results from the Neubauer test which correlated very closely with the results of field fertilizer experiments.

The general relationship between the supply of a given plant nutrient and the amount of growth made by the plant has been expressed mathematically and a method for determining soil deficiencies of plant nutrients developed by Mitscherlich (7). The method has been enlarged upon and the application of this method of mathematical treatment to results obtained in field and greenhouse experiments has been pointed out by Willcox (20).

Murray (8) discussed the applicability of Mitscherlich's law and the method of mathematical treatment of data. He found that phosphate availability depends on the size of the particles in the soil. When

phosphate ions are replaced in the soil solution as rapidly as they are removed, larger applications of phosphate fertilizers give no further increases in yield.

METHODS OF PROCEDURE

A few of the better known and more commonly used methods for determining the fertilizer needs of soils have been considered in this work. The methods studied have been used by different investigators under various conditions and rather widely divergent results have been obtained. It seemed desirable to compare the results obtained by several of the different methods under controlled conditions on a definite soil type. In the work reported here the fertilizer requirements of Carrington loam, with particular reference to the need for phosphates, were determined by various methods.

The nitrogen, phosphorus, and potassium needs of the soil were determined in two experiments by a method similar to that employed by Mitscherlich (7).

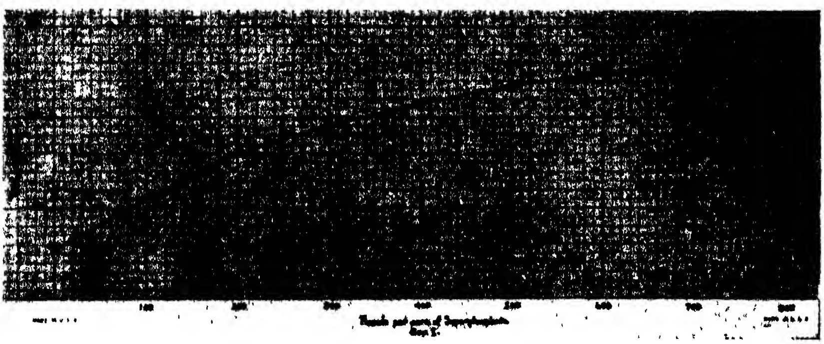

Fig. 1 —Actual and calculated yields in superphosphate-treated soils in tumblers.

EXPERIMENT I

In the first experiment, triplicate 200-gram portions of soil were thoroughly mixed with the fertilizer and placed in glass tumblers. The effect of increasing increments of one fertilizing material was studied in the presence of an adequate supply of the other two materials. The moisture content of the soil was adjusted to 24% and maintained at this amount throughout the experiment. Iowa 105 oats were seeded in the tumblers. When the plants had reached a height of about 6 inches they were thinned to 4 plants per tumbler. After a growing period of 8 weeks the plants were removed, washed, dried 16 hours at 70° C, and weighed.

The treatments and the yields of oats obtained at the end of 8 weeks in this tumbler experiment are given in Table 1. The results secured by experiment and the calculated yields in the superphosphate-treated soils are given in Fig. 1. The results are given as averages of triplicate determinations.

The average yield on the check soil to which no superphosphate was added was 1.11 grams. With 50 pounds per acre of 20% superphos-

phate, a yield of 1.19 grams was secured. With one exception, there was an increase in every case with increased applications of superphosphate and the yields secured were very nearly the same as the calculated values. The soil receiving the 700-pound application of superphosphate per acre yielded only 1.365 grams.

TABLE 1.—*The influence of varying amounts of nitrogen, phosphorus, and potassium on the yield of oats in tumblers.*

Sample No.	Fertilizer treatments in lbs. per acre of 2,000,000 lbs. of soil			Yields in grams
	Sodium nitrate	Superphosphate	Muriate of potash	
1	0	1,000	1,000	1.225
2	50	1,000	1,000	1.340
3	100	1,000	1,000	1.325
4	200	1,000	1,000	1.500
5	300	1,000	1,000	1.465
6	400	1,000	1,000	1.476
7	500	1,000	1,000	1.470
8	600	1,000	1,000	1.550
9	700	1,000	1,000	1.455
10	800	1,000	1,000	1.480
11	1,000	0	1,000	1.110
12	1,000	50	1,000	1.190
13	1,000	100	1,000	1.220
14	1,000	200	1,000	1.370
15	1,000	300	1,000	1.375
16	1,000	400	1,000	1.420
17	1,000	500	1,000	1.500
18	1,000	600	1,000	1.515
19	1,000	700	1,000	1.365
20	1,000	800	1,000	1.560
21	1,000	1,000	0	1.365
22	1,000	1,000	50	1.490
23	1,000	1,000	100	1.335
24	1,000	1,000	200	1.370
25	1,000	1,000	300	1.380
26	1,000	1,000	400	1.430
27	1,000	1,000	500	1.450
28	1,000	1,000	600	1.335
29	1,000	1,000	700	1.245
30	1,000	1,000	800	1.310

When phosphate was available in the soil in adequate amounts, nitrogen and potassium had little effect on the yield of oats.

EXPERIMENT II

In the second experiment the soil was brought into the greenhouse on October 2 and passed through a ¼-inch sieve. The soil was treated in 4-gallon earthenware pots, in two series, one of which was planted to oats and the other kept fallow. The fertilizer treatments are shown in Table 5. The fallow series consisted of one jar each of Nos. 1, 4, 7, 10, 13, 16, 19, and 24 (Table 2), while the cropped series consisted of triplicate pots of each of the 28 treatments. Iowa 105 oats were seeded November 26. The moisture content of the soil was adjusted to 24% and maintained at this amount throughout the

experiment. When the plants were in the boot-stage, they were harvested, dried, and weighed.

The yield curves were calculated by the Mitscherlich formula, using for the effect factor, C, 0.60 for phosphorus. The fallow soils were sampled November 10, 1931, and January 16, 1932, for determinations of available phosphate by the growth of *A. niger* and the Truog method.

The Neubauer method used in this work was essentially the same as described by Neubauer and Schneider (9). Glass dishes about 6 cm high and 11 cm in diameter were made by cutting ½-gallon fruit jars. One hundred grams of the soil to be tested were mixed with 50 grams of washed sand and spread on the bottom of the dish. This was covered with 250 grams of pure quartz sand. The moisture content was adjusted to 50% of the saturation capacity of this mixture. One hundred rye seeds were planted in each dish and allowed to grow 18 days after germination. At the end of this period the seedling plants, both tops and roots, were removed, dried, and weighed. Total phosphorus determinations were made on the plant material obtained. Soils Nos. 1, 4, 7, and 10 only were used in the Neubauer test.

AVAILABLE PHOSPHATES BY THE TRUOG METHOD

The amounts of available phosphate in the various samples taken from the soils in the pots in the greenhouse as measured by the Truog method are given in Table 2.

TABLE 2.—*Phosphate soluble in 0.002 N sulfuric acid.*

Sample No.	Fertilizer treatment in lbs. per acre of 2,000,000 lbs. of soil	Phosphate, p.p.m.	
		Nov. 10, 1931	Jan. 16, 1932
1	Check	12.3	12.5
4	500 lbs. of sodium nitrate	15.7	18.6
7	500 lbs. of superphosphate	28.6	29.6
10	500 lbs. of muriate of potash	11.7	10.3
13	500 lbs. of sodium nitrate and 500 lbs. of superphosphate	18.1	18.6
16	500 lbs. of superphosphate and 500 lbs. of muriate of potash	20.5	21.0
19	500 lbs. of sodium nitrate and 500 lbs. of muriate of potash	6.4	7.4
24	500 lbs. of sodium nitrate, 500 lbs. of superphosphate, and 500 lbs. of muriate of potash	21.0	20.5

Soil No. 4 treated with sodium nitrate contained slightly more available phosphate by this method than the check soil, but soil No. 19, treated with sodium nitrate and potassium chloride, contained only a small amount of available phosphate.

AVAILABLE PHOSPHATE BY THE GROWTH OF *A. niger*

The results secured by the *A. niger* test are given in Table 3.

TABLE 3.—*Available phosphate as shown by the growth of A. niger.*

Sample No.	Fertilizer treatment in lbs. per acre of 2,000,000 lbs. of soil	Weight of mycelial growth, mgm	
		Nov. 10, 1931	Jan. 16, 1932
1	Check	378	268
4	500 lbs. of sodium nitrate	436	301
7	500 lbs. of superphosphate	464	327
10	500 lbs. of muriate of potash	369	251
13	500 lbs. of sodium nitrate and 500 lbs. of superphosphate	480	320
16	500 lbs. of superphosphate and 500 lbs. of muriate of potash	436	324
19	500 lbs. of sodium nitrate and 500 lbs. of muriate of potash	391	238
24	500 lbs. of sodium nitrate, 500 lbs. of superphosphate, and 500 lbs. of muriate of potash	457	330

The largest amount of mycelial growth was secured on the soils treated with superphosphate. The amount of mycelial growth produced was lower in all cases on the soils at the second sampling than on those at the first sampling.

THE NEUBAUER TEST

The results secured in this test are given in Table 4.

TABLE 4.—*Phosphate needs of Carrington loam by the Neubauer method.*

Sample No.	Fertilizer treatment in lbs. per acre of 2,000,000 lbs. of soil	Av. dry weight of plants, mgm	P_2O_5 in plants %	P_2O_5 removed from soil, mgm
0	Quartz sand	886.0	1.010	---
1	Check soil	1171.7	0.885	1.66
4	500 lbs of sodium nitrate	1191.7	0.905	2.05
7	500 lbs. of superphosphate	1315.6	0.960	3.88
10	500 lbs. of muriate of potash	1263.0	0.860	2.13

The rye seedlings removed 1.66 mgm of P_2O_5 from the check soil. Sodium nitrate and muriate of potash increased slightly the amount of P_2O_5 extracted from the soil and the seedlings removed 3.88 mgm of P_2O_5 from the soil receiving the superphosphate.

THE GREENHOUSE POT TEST

The yields of oats from the 4-gallon jars in the greenhouse are given in Table 5. The yields secured on the superphosphate-treated soils and the calculated yields are given in Fig. 2.

Small amounts of nitrogen and potassium brought about increased yields, but larger increases in yields did not accompany the higher applications of these elements. However, regular increases in yields were secured with the application of superphosphate, the actual yields falling close to the curve of calculated yields when calculated according to the Mitscherlich formula.

TABLE 5.—*The influence of varying amounts of nitrogen, phosphorus, and potassium on the yield of oats in pots in the greenhouse.*

Pot No.	Fertilizer treatment in lbs. per acre of 2,000,000 lbs. of soil			Yield in grams dry weight
	Sodium nitrate	Superphosphate	Muriate of potash	
1	0	0	0	8.61
2	100	0	0	11.07
3	200	0	0	16.86
4	500	0	0	8.87
5	0	100	0	18.78
6	0	200	0	20.92
7	0	500	0	24.29
8	0	0	100	16.95
9	0	0	200	10.54
10	0	0	500	11.24
11	100	500	0	24.97
12	200	500	0	21.19
13	500	500	0	25.30
14	0	100	500	13.55
15	0	200	500	14.58
16	0	500	500	24.41
17	500	0	100	7.81
18	500	0	200	10.25
19	500	0	500	8.98
20	100	500	500	25.45
21	200	500	500	26.80
29	300	500	500	28.47
22	500	100	500	13.41
23	500	200	500	18.57
28	500	300	500	24.21
24	500	500	500	26.60
25	500	500	100	22.91
26	500	500	200	26.72
27	500	500	300	29.82

DISCUSSION

The results obtained with these different methods for determining the fertilizer needs of a soil brought out some interesting facts. Applications of sodium nitrate to the Carrington loam gave slight increases in crop yields in most cases. The increases, while probably due to the added available nitrogen, may have been due in part to the increased solubility of the soil phosphates. Sodium nitrate applications increased the amount of available phosphate from 12.5 p.p.m. to 18.6 p.p.m. Thus, the benefit from the nitrogen fertilization may have been an indirect one.

Available phosphate seemed to be the limiting factor in plant growth in this soil. Applications of superphosphate with other fertilizing materials brought about large increases in yield. The amount of available phosphate as shown by the Truog and *A. niger* tests varied with crop yields. That is, all treatments which increased the amount of available phosphate as measured by these methods also brought about increases in plant growth.

Applications of muriate of potash seemed to have little, if any,

beneficial effect on crop growth. Apparently the soil contained an adequate amount of available potassium for the best plant growth.

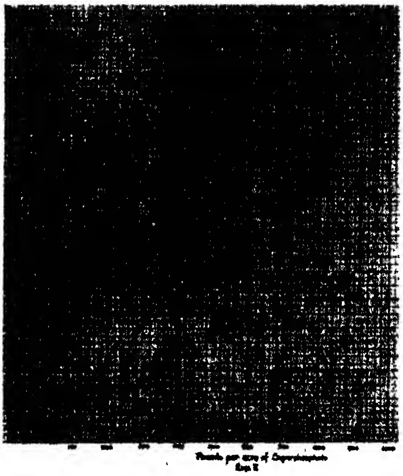

FIG. 2.—Actual and calculated yields in superphosphate-treated soils in jars in the greenhouse.

While this work was not of a sufficient scope to permit of any definite conclusions regarding the absolute value of these methods for determining the fertilizer needs of the soil, it is interesting to compare the results secured by the different methods. The deficiency of available phosphate and the benefit of phosphate fertilization is evident from the results of all the tests. The biological and chemical tests and greenhouse experiments all indicate the same needs of the soil. The results correlate rather closely in the case of this particular soil. However, no predictions can be made with regard to the comparative results to be expected under different conditions or on other soil types.

From these results it would seem that any one laboratory method used might be calibrated or standardized against the crop response to phosphate fertilizers for a given soil. Thus it might serve as a rapid laboratory test for determining the fertilizer needs of that soil.

SUMMARY AND CONCLUSIONS

The fertilizer needs of Carrington loam were studied by means of biological, chemical, and greenhouse tests.

Applications of sodium nitrate alone gave slight increases in the crop yield and brought about an increase in solubility of the soil phosphates.

Twenty per cent superphosphate gave increases in crop yields which varied directly with the amount of the application.

Applications of muriate of potash had no significant effect on crop yields on this particular soil.

The growth of *A. niger* was closely correlated with the amount of available phosphate as measured by the Truog method. There was also a direct relationship between the amount of available phosphate and the crop yield.

The Carrington loam, under the conditions of this experiment, seemed to be adequately supplied with available nitrogen and potassium but showed a deficiency in readily available phosphate for maximum plant growth.

In general, the results secured with the *A. niger* method, the Neubauer test, and the Truog method for available phosphate agreed rather closely with the crop yields obtained in both greenhouse

experiments. That is, increased crop yields were secured on those soils containing the larger amounts of available phosphate.

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THE RELATION OF SOIL ACIDITY TO THE DECOMPOSITION OF ORGANIC RESIDUES[1]

CHARLES THOM AND N. R. SMITH[2]

Acidity as a limiting factor in the distribution of organisms is generally recognized. In a study of the natural distribution of plants, Wherry (8)[3] has done a conspicuous service in tracing the correlation between particular species of flowering plants and soil areas showing specified ranges of acidity. Gainey (2) has followed Azotobacter all over the state of Kansas and shown that it is absent or inactive in soils more acid than pH 6. Within the laboratory, the pH optima for large numbers of micro-organisms have been satisfactorily established.

In transferring culture operations from the laboratory to field soil which presents much more complex relations, it has been common to assume that a pH determination of a representative sample would show the range of micro-organic activity which might be anticipated. The buffer capacity of the soil was assumed to be great enough to dispose of most local influences. Therefore, great contrasts in micro-population associated with soil type were expected. Nevertheless, we all knew that decompositions did occur in all kinds of soil and that the general nature of the nitrogen and carbon transformations accomplished by them somehow reached about the same group of end products. It was assumed, however, that the results observed were brought about by different micro-organic complexes. Then Conn (1) interjected his observation that when he had laboriously compared his bacteriological findings from a long series of soil types he found much the same flora in them all.

Some other explanation was necessary. To reach some definite basis for finding out just what occurs, Smith and Humfeld (5) selected two quite acid soils of contrasting texture, *viz.*, Collington fine sandy loam and Leonardtown clay loam, and moved sufficient of them into a series of greenhouse plats to make extensive comparisons. The plats were alternately left natural and limed to about pH 6.8. Thus they formed a favorable basis for a painstaking study of just what types of decomposition appear in organic materials left to decay in contact with soils differing only in acidity.

In their first experiment, Smith and Humfeld reported bacteriological studies of succulent rye grown elsewhere and added as green manure to plats of Leonardtown clay loam. They tested samples taken at intervals over a period 56 days.

The acidity of unlimed controls was pH 4.6. The total count of bacteria per gram in these control plats ranged from about 15 millions at the start to 20 millions at the end of the period. The limed plats showed pH 6.5 to 7.1, with total counts per gram of bacteria ranging

[1]Contribution from the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Washington, D. C. Publication No. 1067. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication October 8, 1932.

[2]Principal Mycologist and Senior Bacteriologist, respectively.

[3]Reference by number is to "Literature Cited," p. 396.

from about 18 or 20 millions to about 60 millions at 56 days. The general level of bacterial population at the end of the period was about twice as high in limed as in unlimed plats. Addition of succulent rye raised the count in 4 days to 116 millions in unlimed and 151 millions in limed plats. These figures dropped to 41 and 56 millions, respectively, 3 days later. The green manure disappeared almost as quickly in one plat as in the other. In the acid or unlimed plats the figures for organisms stayed low, but in the limed plats there was a marked rise in general level of bacterial activity up to the end of the period.

The first experiment thus opened up a new series of questions which called for altered procedure. In the second experiment cores were taken with the sampling tube, as in the first experiment. Each core was divided into the top 2 inches, the 2 to 4 inch segment, and the 4 to 6 inch segment containing the green manure. Then the 4 to 6 inch subsample was separated and the remnants of the green manure were picked out as free from soil as possible and studied separately. The findings were tabulated and published by Humfeld and Smith (3). A few striking relations were developed. The unlimed soil in all subsamples in the three layers ranged from pH 3.9 to 4.4 at the fourteenth day, except pH 4.8 in one containing green manure. From the limed plat, the whole series of subsamples ranged from pH 6.8 to 7.3. The green manure from the unlimed plat with adhering soil particles as picked at the first sampling was pH 6.8 from which figure it dropped irregularly until the fifty-sixth day when the trace remaining had reached pH 4.3. On the limed sample the pH showed minor variations, beginning at pH 6.7 and ending at the fifty-sixth day with pH 6.8. The bacteriological figures from the same subsamples were equally striking.

In the unlimed samples (pH 3.9 to 4.4), the total colony counts in the three subsamples of each core (0 to 2, 2 to 4, and 4 to 6 inches) were fairly consistent and mostly showed a slight increase in the 4 to 6 inch section containing some remnants of the green manure. These totals for the acid soil ranged from 3.7 to 27.5 millions. In contrast, the limed soil showed subsamples ranging from 23.8 to 75 millions, an average of about 3 times the total population figure in the acid subsample. The vetch used was grown in the greenhouse and had slimy and decaying leaves in contact with the soil. The figures started with 970 millions to the gram of green vetch calculated to the dry basis, jumped in 4 days to 21,500 millions in the subsample from the unlimed plat, and 46,400 millions in the subsample from the limed plats, then dropped to 73.5 and 87.6 millions in the samples after 56 days.

In brief, in this experiment, the green manure went through approximately the same rotting process in soil at pH 4.2 to 4.8 that it did at pH 6.5 to 7.3. The pH of the green manure was not markedly affected by contact with the soil until decomposition had reached what we may call the liquefaction stage with osmotic relations established with the surrounding soil.

Another series of samples was taken by Humfeld to obtain a comparative picture of decomposition occurring on the surface of the

soil in contrast to green manure plowed in. The plat was Keyport clay loam which tested pH 6.6 to 7.0. Sampling began with materials scattered upon the surface, then took the first quarter inch, the second quarter inch, the second half, and the second inch of the top soil with findings as indicated in Table 1.

TABLE 1.—*Keyport plat, pH 6.6 to 7.0, with green vetch added upon the surface at start and at 11 days decomposition at about 28°C.**

Sample	Fungous colonies		Bacterial colonies	
	At start	After 11 days	At start	After 11 days
Green vetch..	363,000	28,580,000	159,000,000	8,900,000,000
0–¼ in	834,000	1,410,000	142,000,000	65,200,000
¼–½ in......	288,000	326,000	60,000,000	55,300,000
½–1 in.......	297,000	298,000	37,800,000	36,500,000
1–2 in.......	238,000	220,000	42,200,000	32,100,000

*Cultures and tabulations by Dr. Harry Humfeld.

Here again the decomposing mass gives colony counts which jump into the billions to the gram in cultures for bacteria, while the mold colonies appear in millions. Other micro-organisms were significantly abundant. The striking feature of the figures lies in the narrowness of the zone or layer of soil affected by the decomposition process. The micro-organic population of soil at a depth of ½ inch was practically unaffected by the rotting of the mass of vetch upon the surface. Conversely, the soil affected the aerobic decomposition process upon its surface as little as it affected the rotting process at the 5-inch layer. One has but to glance at the load of micro-organisms carried by the product at the outset to see that no inoculation is necessary. Those familiar with bacteriological reports on forage and food products will find the figures for these green products in harmony with other figures already well known.

The same general type of aerobic decomposition found in this experiment is characteristic of the decay of crop residues which are left upon the surface of the soil through the fall and winter. It is found to some extent in the meadow and pasture, the waste place, and the fence corner. It characterizes the decay of plant remains upon the surface of virgin soils wherever found. Such aerobic decomposition then is largely independent of the activity of the soil underlying the decaying plant or animal material.

From another angle, plants in the field and the greenhouse have been dug and studied by Starkey (6) and by Thom and Humfeld (7). Starkey showed that the micro-organic changes in a soil due to the growth of green plant roots was practically confined to an infinitesimal zone of actual contact. After Humfeld had obtained similar bacteriological findings from one series of samples, he took another series of samples of corn roots from the soils of markedly different acidity and tested them carefully for pH value. The results showed that this little zone of activity where the green plant protoplasm and its envelope of micro-organisms operate together presents a pH favorable for both—that is, less acid in very acid soil and less alkaline

in the alkaline soil. If then the green plant can grow at all in either extreme type of soil, it is because the actual area of growth is transformed by the growing plant alone or with its associative organisms to a condition tolerated by both. That zone of tolerance differs with the species, but its existence and the ability of the plant within limits to make its own environment is the outstanding feature of this group of observations.

In large measure, such root systems ramifying into the soil as figured by Weaver and others decay equally independently of the soil. After their decay, such roots often leave tubes lined with traces of more or less recognizable organic remains which are often followed for considerable distances by new roots of the same or other species. Since crop residues, dead vegetation, forest litter, and the major fraction of many root systems all contribute to the organic factor in the surface 6 inches of soil, these observations are strictly in harmony with the curves prepared from samples of six types of virgin soil and exhibited by Marbut (4) in 1929.

Manifestly, the local change or local maintenance of biologically favorable conditions has its limit of operation dependent, perhaps, for growing crops on soil pH and on soil moisture, or for dead and decaying material upon the nature of the decaying matter itself.

The tolerance anticipated must depend also on the nature of the alkalinities or acidities encountered and upon the moisture present as favoring or interrupting osmotic activities. If moisture enough is present to establish and maintain rapid osmotic activity at all times, the pH of the soil will interfere with the local biological processes much more than when soil moisture is normal or low.

In any case, it is necessary to get away from the idea that we can go into a field, take a sample of the top 6 or even 9 inches with a soil tube, homogenize the sample, and determine its pH, then make a total count of the micro-organisms present and have a real picture of what is going on in that field. The very care with which we are warned to take such samples, combine them, and homogenize them for examination is recognition of the fact that the soil does not present a homogeneous biological entity, but a diversity. In this heterogeneous mass then, we may have whole series of complex biological activities going on at one time. Many of these activities are localized about or within some determining agent which might or might not appear in the ordinary aliquot taken for test.

SUMMARY

Experimental work designed to define the relation of soil acidity to the decomposition of organic remains is reviewed. Organic substances subjected to decomposition in connection with the soil include (a) material distributed over the surface and left to decay there; (b) masses plowed under; and (c) roots of green plants distributed through the soil by their method of growth. Intensive study of the microbic factors involved in these decomposition processes have brought out certain points of considerable interest, as follows:

1. Total plate counts of micro-organisms in acid and limed plats of the same soil without other treatment show the general level of

microbic activity in the limed plats to be about 2 to 3 times that of the acid plats.

2. Organic remains upon the surface break down by aerobic activities which involve enormous numbers of bacteria, fungi, and other organisms, without correlated effects upon the micro-population of the underlying soil.

3. Green manures plowed into soils in good tillable condition are broken down principally by bacterial activity without affecting or being affected by the acidity of the surrounding soil.

4. Growing root systems surrounded by very narrow zones of microbic activity give pH tests at least partially independent of the adjacent soil, hence present biological conditions determined by their own acidity, rather than that of the soil.

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SYMPTOMS OF FERTILIZER INJURY TO POTATOES[1]

John Bushnell[2]

Experiments on machine placement of fertilizers for potatoes are being conducted by several experiment stations in cooperation with the U. S. Dept. of Agriculture and the National Fertilizer Association.[3] At the outset, in 1931, it was conceded that fertilizer in contact with seed pieces would have some detrimental effect. This opinion was based upon the work of Coe[4] in New Jersey and that of Truog, *et al.*,[5] in Wisconsin, who reported reduced stands and retarded emergence from contact placement. It was surprising, therefore, in the Ohio tests of 1931 to find no detrimental effects whatever from contact placement and in 1932 only retarded emergence and some weak hills without significant reduction in stand.

Truog and his co-workers also reported that potato sprouts are relatively sensitive to fertilizer salts and hence advised against placing fertilizer above the seed where the sprouts would encounter it. Such a placement was included in the 1932 Ohio tests and proved to be more detrimental to the stand than the contact placement. Incidental examination of missing hills, however, disclosed no injury to the sprouts; instead, the seed pieces had rotted. The majority of hills (more than 80%), however, had sturdy plants with no indication of any injury from the fertilizer. In these tests a 4–10–6 fertilizer was used at the rate of 1,500 pounds per acre. Details are reserved for a later publication.

Since these observations were not in accord with the literature, it seemed advisable to study in more detail the nature and symptoms of fertilizer injury to potatoes under Ohio conditions. Small, hand-placement experiments were therefore planted on the experiment farm at Wooster during the summer of 1932.

VARIOUS PLACEMENTS OF MIXED FERTILIZER WITH WHOLE TUBERS AND CUT SEED PIECES

The first series aimed to imitate machine types of placement, the fertilizer being laid in a band at various levels close to the seed pieces.

[1]Contribution from the Department of Horticulture, Ohio Agricultural Experiment Station, Wooster, Ohio. Also presented before the Joint Committee on Fertilizer Application at Washington, D. C., November 16, 1932. Received for publication October 24, 1932.

[2]Associate Horticulturist.

[3]The experiments with machine fertilizer placement on potatoes were undertaken at the suggestion of the Joint Committee on Fertilizer Application whose membership is drawn from the American Society of Agronomy, the American Society of Agricultural Engineers, the National Fertilizer Association, and the National Association of Farm Equipment Manufacturers. For helpful suggestion on the hand placement work reported herein, the writer is particularly indebted to R. M. Salter, chairman of the committee in 1932 and agronomist of the Ohio Agricultural Experiment Station.

[4]Coe, Dana G. "Ammo-phos"—Its effect upon seed germination and plant growth. N. J. Agr. Exp. Sta. Bul. 375. 1923.

[5]Truog, E., Harper, H. J., Magistad, O. C., Parker, F. W., and Sykora, James. Fertilizer experiments: Methods of application and effect on germination, early growth, hardiness, root growth, lodging, maturity, quality and yield, Wis. Agr. Exp. Sta. Res. Bul. 65. 1925.

A remnant of the 4–10–6 fertilizer from the machine tests was used. According to B. E. Brown of the U. S. Bureau of Chemistry and Soils, who furnished it, this fertilizer was made up of the following ingredients:

Sodium nitrate	6.3%
Ammonium sulfate	9.5%
Dried blood	7.4%
Superphosphate, 16.5%	60.4%
Muriate of potash	12.4%
Sand	4.0%

Application was made at the rate of approximately 1,500 pounds per acre in rows 32 inches apart, the actual amount being 1 pound to each 130-inch row. The placements were as follows:

1. One-half inch under the seed pieces.
2. One-half inch above the seed pieces.
3. Contact on under side of seed pieces. With the cut seed, the freshly cut surface was set downward in direct contact with the band of fertilizer.
4. Contact on upper side. With cut seed, the cut surface was placed upward so that the fertilizer lay on the exposed surface.
5. Seed wet and coated with fertilizer prior to planting, the remnant of fertilizer not adhering to the seed being spread in the row as in placement 4. This was not an imitation of machine methods but was a procedure designed to cover all of the eyes of the seed with fertilizer.

The seed tubers were Russet Rural of small size, ranging from 1 to 2 ounces, the smaller size being planted whole and the larger cut in half. The tubers had been taken from storage in late May and exposed outside to green, a method of preserving seed for late planting commonly used in Ohio. Consequently, the tubers were somewhat shrivelled with a leathery skin and had typical, short, green sprouts. These sprouts were carefully rubbed off before planting.

The soil, a Volusia silt loam, was slightly moist when the furrows were opened, but by the completion of the planting operations it was dust dry. To encourage re-establishment of capillarity the rows were firmly packed with a hoe after planting. Five days later, June 26 and 27, there was a rainfall of 2.69 inches, and again on July 7 there was a rain of more than an inch.

On July 12, when most of the sprouts had emerged, the entire planting was dug to allow for examination of the sprouts and seed pieces. The longest sprouts on each were measured to the nearest centimeter.

Two distinct types of injury were conspicuous. First, the halved tubers with the cut surfaces in contact with fertilizer were seriously shrunken, indicating that the surface had not healed, that water had been withdrawn, and that the tissues were killed as a result. The general appearance of the cut pieces with their sprouts is shown in Fig. 1, with the shrunken edge shown in more detail in Fig. 2. In some instances (Table 1), the pieces were completely killed by contact with the fertilizer, apparently so rapidly that no sprouts developed sufficiently to survive. On many others the sprouts were distinctly

slender, indicating that destruction of the tissue had proceeded to the point where the remainder of the piece was inadequate to nourish the sprouts.

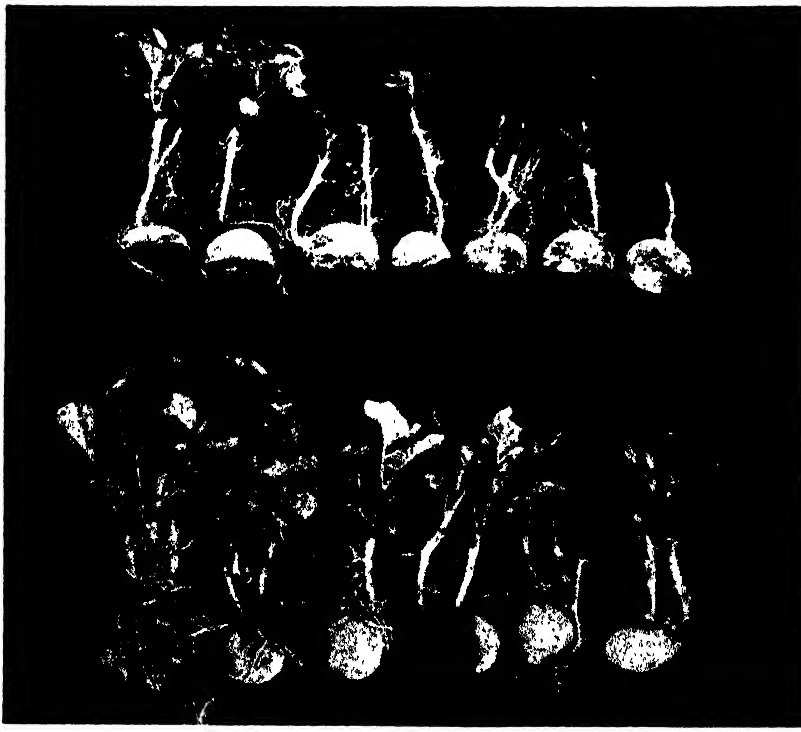

FIG. 1.—Effects of 4–10–6 fertilizer at 1,500 pounds per acre in contact with seed. Cut seed (upper row) injured at cut surfaces, whole tubers (lower row) uninjured.

TABLE 1.—*Effect of fertilizer placement on size of sprouts and rotting of cut seed pieces.**

Placement of fertilizer with reference to seed	Ave. length of longest sprouts cm		Cut seed classified according to extent of rot			
	Whole seed tubers	Cut seed pieces	None %	Slight; sprouts sturdy %	Considerable; sprouts slender %	Complete; no sprouts %
1. In band ½ inch under....	10.8	9.6	33	54	13	0
2. In band ½ inch above....	10.8	9.9	7	76	17	0
3. In contact on under side†	10.5	8.1	0	40	57	3
4. In contact on upper side‡	9.9	7.0	0	27	63	10
5. Coated on wet seed......	8.5	7.5	0	13	67	20

*1,500 pounds per acre of 4–10–6 applied at planting, June 21. Measurements July 11. Average of duplicate plats of 20 seed pieces.

†Cut surface placed downward in contact with fertilizer.

‡Cut surface placed upward in contact with fertilizer.

This serious destruction of the seed was confined to the cut pieces. None of the whole tubers showed any lesions or soft spots which might be classed as local injury. As a matter of fact, the whole tubers were extremely firm and turgid, much more so than when planted. In spite of the presence of the fertilizer, irrespective of its location, the whole tubers had evidently absorbed moisture from the soil.

FIG. 2.—Shrivelling at cut surface resulting from contact with fertilizer.

The second type of injury noted was that the fertilizer in contact with the seed affected the length of the sprouts. Although the whole tubers themselves were swollen and turgid when surrounded by fertilizer, the sprouts on them had not made as rapid growth as where the fertilizer was a little distance away. This is shown in the average length of sprouts reported in Table 1.

A surprising feature of this first series was the absence of local injury to the sprouts or roots. Sprouts extended directly through the band of fertilizer placed one-half inch above the seed tubers, and roots developed in this band without any browning, lesions, or other visible abnormality whatever.

FERTILIZER CONSTITUENTS IN CONTACT WITH SEED TUBERS

Immediately after planting the preceding series, a series was started with the three common constituents of potato fertilizers, namely, sulfate of ammonia, superphosphate, and muriate of potash

The aim was simply to determine the degree of injury caused by each fertilizer constituent when in contact with the seed tubers and to ascertain whether specific symptoms were associated with specific fertilizers.

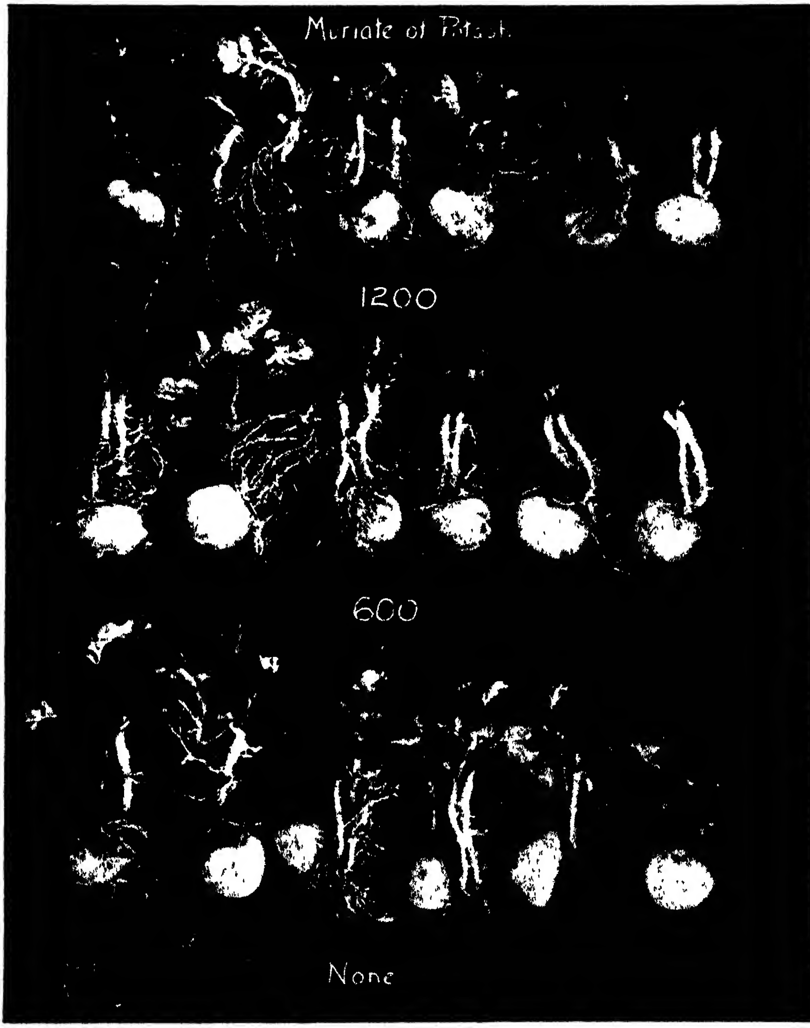

Fig. 3.—Sprouts from seed tubers in contact with muriate of potash. Growth retarded, otherwise no injury. Labels show rates of application in pounds per acre.

The plats were adjacent to those of the preceding series. Small, whole tubers were used exclusively, with the fertilizer spread directly on them in the row—placement 4 of the preceding series. The planting was in duplicate, and the procedure was the same as in series I.

As shown in Table 2, sulfate of ammonia and muriate of potash considerably retarded the sprouts. Typical effects from muriate of

potash are illustrated in Fig. 3. The effect was more pronounced than with the 4-10-6 mixture (Table 1, placement 4), even though the application was lighter. With superphosphate, on the other hand, no reduction in growth of the sprouts was produced.

At the heavier applications of sulfate of ammonia and muriate of potash, some of the seed tubers failed to become turgid. A rough classification was made by feeling the tubers with the fingers and is reported in Table 2 as percentage of turgid tubers. Those classed as "not turgid" had swollen some since planting but evidently had been hindered to some degree in the absorption of soil moisture by the presence of the fertilizers.

The detrimental effects were most pronounced in an area of higher and drier soil in the north section. The differences are reported in Table 2 and illustrated in Fig. 4.

The results as a whole from this first and second series indicated that the detrimental effects were largely osmotic. The more soluble the fertilizer, the larger the quantity, and the drier the soil, the more sprout growth was retarded and the swelling of the tubers impeded.

TABLE 2.—*Effects of fertilizer constituents in contact with whole seed tubers, June 21 to July 11.*

Rate of application in lbs. per acre	Average length of sprouts, cm			Percentage of turgid tubers		
	South series	North series	Average	South series	North series	Average
			Sulfate of Ammonia			
None	10.9	9.8	10.4	100	100	100
300	10.3	9.1	9.7	100	100	100
600	8.2	7.2	7.7	93	93	93
900	6.3	6.6	6.5	80	67	73
1,200	5.5	5.6	5.6	53	47	50
			Muriate of Potash			
None	11.0	9.2	10.1	100	100	100
300	10.5	8.3	9.4	100	100	100
600	8.9	7.1	8.0	93	67	80
900	8.3	6.7	7.5	100	33	67
1,200	7.1	6.1	6.6	73	33	53
			Superphosphate, 20%			
None	10.5	9.5	10.0	100	100	100
300	11.0	9.7	10.4	100	100	100
600	11.0	9.7	10.4	100	100	100
900	10.8	10.3	10.6	100	100	100
1,200	10.2	10.6	10.4	100	100	100

INJURY TO SPROUTS FROM FERTILIZER ABOVE SEED

Since Truog and his co-workers reported that potato sprouts were readily injured by contact with the fertilizer and since no injury of this type was observed in the preceding experiments, a third series was planted on July 18 with fertilizer placed a half inch above the seed tubers.

Instead of spreading the fertilizer in a band, a weighed amount was placed in a disk directly above each tuber. The same fertilizers were used as in the preceding work. The amount above each tuber varied by 7-gram intervals from 7 to 28 grams, except in the case of the superphosphate where the amounts were doubled. To insure proper placement, the forefinger of the left hand was kept on each tuber while soil was drawn over the tuber to a depth of about a half inch; then a metal ring 3 inches in diameter was centered at the mark of the forefinger and the weighed amount of fertilizer spread within the ring. The ring was then removed and used at the next seed. After all of the fertilizer was thus placed, soil was carefully drawn over it to a depth of about 1½ inches.

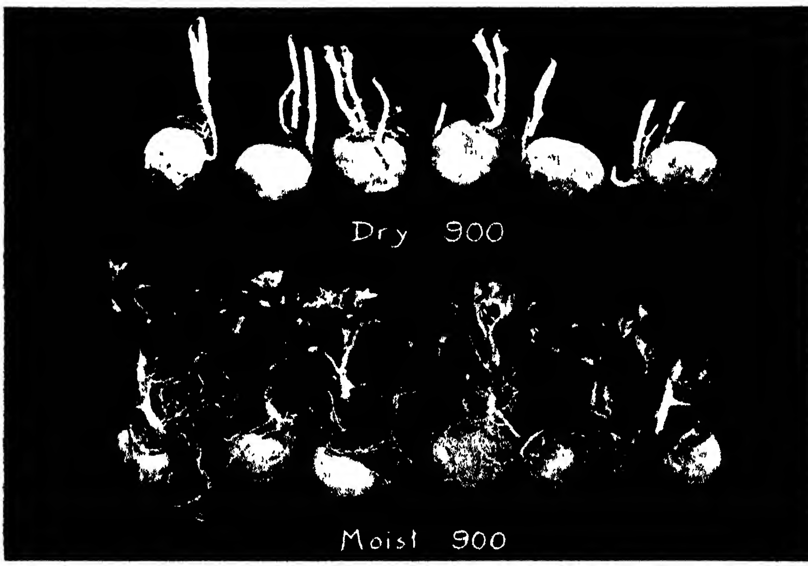

FIG. 4.—Sprouts and roots more retarded in dry than in moist soil by muriate of potash in contact with seed tubers at rate of 900 pounds per acre.

An application of 7 grams to 3 inches of row is approximately 1,000 pounds of fertilizer per acre if spread in a continuous band. Thus, the amounts used here approximated a 3-inch band placement of 1,000 to 4,000 pounds per acre (2,000 to 8,000 pounds of the superphosphate).

The soil at the time of planting appeared to be as dry as that used for the earlier series. On the third and fourth days the rainfall was 0.85 inch. After this no rain fell sufficient to wet the soil to the depth of the fertilizer. As it was midsummer, the shortage of rain resulted in severe drouth.

The conspicuous feature of this series was the severe injury to the sprouts. Sulfate of ammonia in particular, even at the smallest application, killed the tips. As shown in Fig. 5, after the tips were killed the sprouts branched below the injury. These branches in turn

were killed at the tips, unless they extended horizontally far enough to escape the disk of sulfate of ammonia.

Muriate of potash, as shown in Fig. 5, did not kill the tips to the same degree but caused a characteristic swelling of the stems where they extended through the fertilizer. The swelling extended above and below the original horizon at which the fertilizer was applied, probably due in part to movement of the fertilizer. With the 4-10-6 mixture, the sprouts were likewise injured but to a smaller degree.

TABLE 3.—*Effects of fertilizer placed in disks about one-half inch above seed tubers, July 18 to August 15.**

Amount of fertilizer above each seed tuber in grams†	Sulfate of ammonia		Muriate of potash		Superphosphate 20%		4-10-6 mixture	
	South	North	South	North	South	North	South	North
	Percentage of Seed Tubers With Sprouts Killed at Tip							
7	68	100	0	11	0	0	0	7
14	78	100	12	31	0	0	5	7
21	100	100	30	72	0	0	17	24
28	100	100	40	88	0	0	20	35
	Average Length in cm of Longest Uninjured Sprout on Each Seed Tuber							
0	13.7	12.7	12.8	12.0	15.7§	13.0	12.1	12.2
7	12.2	——‡	11.2	11.0	15.1	12.6	11.6	10.2
14	11.0	——‡	10.8	9.5	15.2	12.4	12.0	8.3
21	——‡	——‡	10.6	9.4	14.9	11.8	11.1	7.7
28	——‡	——‡	9.8	9.5	14.7	12.1	10.9	7.6

*Duplicate planting, soil in north section somewhat drier than in the south.
†Double these amounts for the superphosphate.
‡No uninjured sprouts to measure.
§Large size of sprouts in this section probably due to favorable soil moisture.

The superphosphate, even at these enormous applications, did not kill the tips or produce any appreciable swelling. The only effect was a small but measurable retardation in growth of the sprouts. This is in contrast to the preceding series where no effect on growth was observed. The average length of sprouts, together with the percentage of tubers with injured sprouts, is given in Table 3.

In the case of the fertilizers which killed the tips of sprouts, the effect on the length of sprouts was determined from those that escaped tip injury. Thus, with the sulfate of ammonia the length of sprout could only be determined for the two smallest rates of application. The data in Table 3 show that sprout growth was seriously retarded by the readily soluble fertilizers, even more retarded than in the preceding series.

Throughout this series there was considerable rotting of the seed tubers, due presumably to the lateness of planting and to the severe, hot weather. The proportion of rotted tubers, however, was approximately the same in the unfertilized and the fertilized sections; hence, the counts are omitted here.

ABSORPTION OF MOISTURE BY WILTED SEED TUBERS

To determine more definitely the effect of contact of fertilizer on the initial swelling and sprouting of wilted seed tubers, a small supplementary experiment was planted on July 19. Small, whole tubers were placed in contact with a 4–10–6 fertilizer, as in placement 4 of the first series, at three rates, *viz.*, 500, 1,000, and 2,000 pounds per acre. The soil was dust dry, the weather hot, and the only rain was 0.85 inch on the second and third days after planting.

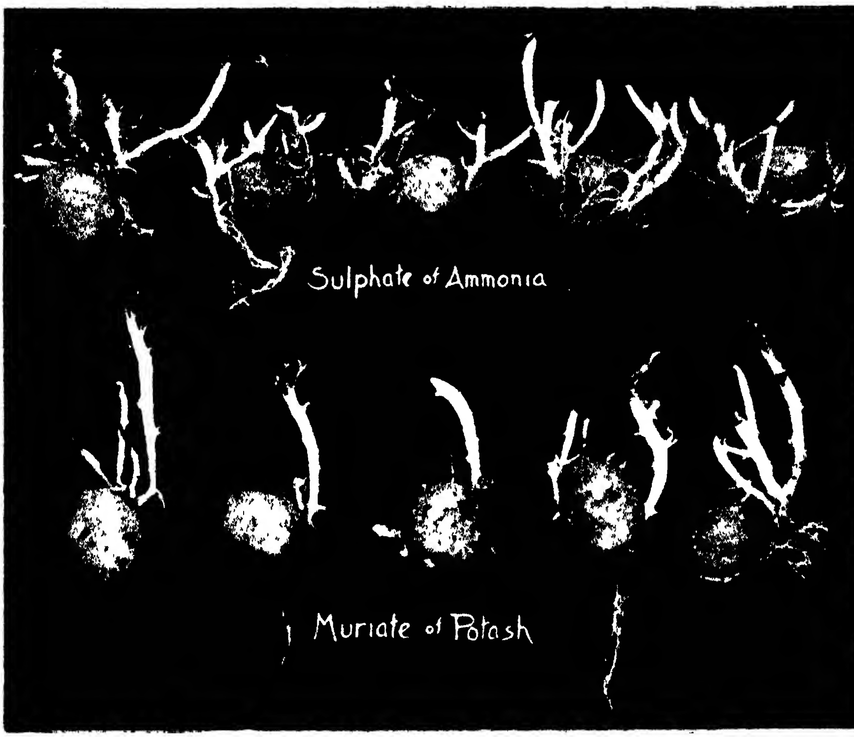

FIG. 5.—Injury to sprouts during drouth from fertilizers above seed tubers.

The tubers were weighed individually to the nearest gram when planted and again 8 days later. Of the 20 tubers in each plat, about a third started to rot. The proportion rotted was no higher in the fertilized than in the unfertilized checks. The weights, as given in Table 4, were calculated from the unrotted tubers.

When examined, none of the tubers were turgid and swollen as found in the other experiments, but fertilizer differences were evident. At the two larger applications, the tubers had actually lost weight, whereas those in the unfertilized plats had started to swell (Table 4).

All of the tubers had sprouted, but the sprouts were distinctly longer on the unfertilized plats. Instead of attempting to measure accurately the very small sprouts, they were simply classed as longer

or shorter than 3 mm. These counts are also included in Table 4. It is of interest to note that although the tubers had lost weight in the presence of fertilizer they had started to sprout.

TABLE 4.—*Absorption of soil moisture by wilted seed tubers in contact with a 4-10-6 fertilizer, July 19 to 27.*

Fertilizer in lbs. per acre	Increase or decrease in weight per seed tuber, grams	Seed tubers with 3 mm sprouts %
0	0.7	100
500	0.1	100
1,000	—0.3	60
2,000	—1.9	20

That wilted tubers will absorb water from fairly high concentrations of salt was further demonstrated in a small laboratory experiment. Seed tubers were soaked for 4 days in a range of sodium chloride solutions. Because the shrivelled surface made it difficult to dry the tubers for weighing, they were merely wiped with a towel and weighed to the nearest gram. Three were soaked in each beaker of solution. The results are given in Table 5. At salt concentrations of less than 5% the tubers increased in weight, presumably from absorption of water; whereas, in concentrations above 5%, they decreased in weight.

TABLE 5.—*Water absorption by wilted tubers in salt solutions, July 13 to 17.**

Concentration of salt solution %	Weight of three tubers, grams		Increase or decrease in weight, grams
	Original	Final	
0	116	122	6
1	140	144	4
2	138	141	3
4	115	116	1
6	121	120	—1
8	125	123	—2
10	135	131	—4

*Three small tubers in each sodium chloride solution.

DISCUSSION AND CONCLUSIONS

From these observations it is evident that the above-ground symptoms of injury from fertilizer, what may be termed the "field" symptoms, may appear in one or more of three forms, as follows:

1. Retarded emergence of sprouts. From the present observations this would be expected to be the most common and most characteristic symptom.

2. Production of weak, slender plants, due to the rotting of cut seed pieces.

3. Reduction of stand, due to very rapid rotting of cut seed or to killing of sprouts as they encountered the fertilizer. These severe

types of injury would be expected only where large amounts of fertilizer were placed in contact with or above the seed.

It is an important practical conclusion that cut seed is more likely to be injured by improper placement of fertilizer than whole seed. At present, cut seed is used predominantly in North America, but there is a gradual trend, at least in Ohio, toward the use of small whole tubers.

Finally, it might be mentioned that fertilizer injury to potatoes is not serious in Ohio and westward, except on very sandy soils, due, in part, to the smaller applications of fertilizers as compared with those used in the eastern states, and, in part, to the higher proportion of superphosphate in the mixtures. It is also probable that slight injury has been overlooked because of the failure to recognize retarded emergence of sprouts as a symptom of injury. As large applications become more common, and mixtures higher in soluble constituents are adopted, we may expect the problem of proper placement to become more important.

SUMMARY

Four distinct effects were observed from fertilizer placed in close proximity to potato seed pieces or to small, whole seed tubers in a silt loam soil, as follows:

1. The most common detrimental effect was a retardation of sprout growth without other visible injury to the seed, sprouts, or roots.
2. The normal absorption of soil moisture by wilted seed tubers was impeded.
3. Under drouth conditions, fertilizer in a band above the seed killed or injured some of the sprouts where they encountered the fertilizer.
4. Fertilizer in contact with freshly cut seed prevented normal healing, apparently withdrawing water from the cut surface and, thus, destroying a portion of the seed piece. Many of the sprouts were slender, typical of those from inadequate seed pieces. Small, whole seed tubers escaped this type of injury.

All of these effects are considered to be primarily osmotic, rather than specific chemical effects. The more soluble the fertilizer used, the larger the application, and the drier the soil, the more serious was the injury.

THE TAXONOMY AND MORPHOLOGY OF BULBOUS BLUEGRASS, *POA BULBOSA VIVIPARA*[1]

MORRIS HALPERIN[2]

One of the first intimations in the literature as to the existence of the proliferated form of *Poa bulbosa vivipara* is that given by Scheuchzer (1),[3] "....*Locustae*...*quodam veluti bulbulo foliola*...prodeunt." Linnaeus (2) cites Scheuchzer's work in connection with the grass which he names *Poa bulbosa*. Munro (10), in his report on the identification of the grasses in Linnaeus' herbarium, states, regarding the material of *Poa bulbosa*, "All viviparous except one specimen with very narrow leaves and extremely similar to *P. ligulata* Boiss." Linnaeus, however, does not mention the proliferated form.

Koeler's (3) description of this form is essentially a statement to the effect that, in the variety, the ovary is transformed into a bulbil. Desmazieres (4) in his description of *Poa bulbosa* states: "Les valves sont membraneuses en leurs bords, et s'élongent quelquefois en manière de feuilles, de sorte que la panicule paroit feuillée, chévelue, et comme frissée." Desmazieres does not, however, designate this form by a varietal name, nor was he apparently aware that Koeler (3) had so designated it a few years earlier. Mertens and Koch (5) mention var. *vivipara*, merely stating that this form, in which the florets are changed into leafy bulbils, occurs more frequently than does the normal form.

Döll (8) observed that whereas the normal form does not have glabrous lemmas, the proliferated form often does. Hein (11) noted that *Poa bulbosa* occurs in a viviparous form in which the florets are transformed into leaf-like bulbils. The proliferated form is mentioned with little or no taxonomic data by Kunth (6), Reichenbach (7), Koch (9), Boissier (12), Harz (13), Sowerby (14), Schwarz (15), Post (16), Ascherson and Graebner (17), Koch (20), Correvon (21), Vilmorin (23), Kunzel (24), Piper (26), and Witmack (28).

Kennedy (30) gives a botanical description headed "*Poa Bulbosa*," but with no separate description of the proliferated form. He does, however, describe and illustrate well the morphology of the proliferated florets and of certain tissues found in the rudimentary plant represented by the bulbil.

The writer, who has had opportunity to observe this grass in the Pacific Northwest of the United States during 1929–31, has made a study of his own collections of *Poa bulbosa* var. *vivipara* as well as of

[1]Contribution from the Division of Agronomy, College of Agriculture, University of California, Berkeley, Calif. Received for publication October 25, 1932.

[2]Research Assistant; now Research Assistant in Botany, University Farm, Davis, Calif. The Division of Plant Pathology, University Farm, Davis, California, has kindly permitted the use of its micro-photographic apparatus, and Dr. J. B. Kendrick assisted by Mr. A. E. Davey, both of that Division, have very obligingly made the photograph represented in Fig. 1. The herbaria mentioned herein have been helpful in making their specimens accessible for the present study. Thanks are gratefully expressed here to Mrs. Agnes Chase, of the Grass Herbarium of the United States National Museum, for her critical reading of the manuscript.

[3]Reference by number is to "Literature Cited," p. 412.

undescribed collections by others, with a view to formulating at least a preliminary description intended to include all the data available at present.

THE NOMENCLATURE OF THE PROLIFERATED FORM

Poa bulbosa L. var. *vivipara* Koeler (3), 1802.
Poa prolifera Schmidt in Mayer, Samml. Phys. Aufs. I, 188, 1791. (In Hegi (19).)
Poa crispa Thuill., La Flore des environs de Paris. ed. II, 45, 1799. (In Hegi (19).)
Poa bulbosa L. var *vivipara* Hein (11), 1877.
(*Poa bulbosa* L.) var. *vivipara* L., Harz (13), 1885.

Kennedy (30), referring to European material, and Halperin (31, 32), to American material, have reported that specimens are frequently found which contain both normal and proliferated florets. The writer has used the specific name for all material containing any normal florets whatever and therefore for material containing both kinds in the same spikelet or panicle, and proposes to reserve the varietal name for material in which all the florets are proliferated. It is recognized, however, that this designation is purely arbitrary. It is also apparent that the proliferated form is probably not a true variety differing from its species in a definite genetic characteristic, but is rather a phase which appears under certain environmental conditions not yet definitely known.

FIG. 1.—A proliferated spikelet.

PROLIFERATION IN *POA BULBOSA*

Proliferation in grasses, as defined by Hitchcock (22) and Armstrong (25) and as understood here, is the condition in which the floral organs or bracts have been transformed into a bulbil. The term "bulbil" is used in this sense by Ward (18). The bulbil in *Poa bulbosa* contains all the tissues necessary for propagating the plant, the bulbils, in fact, being used as "seed" to obtain agricultural plantings of this grass. As Kennedy (30) has indicated, the palea is wanting in the proliferated florets; the lemma is present and loosely surrounds the bulbils (consisting of the transformed stamens and pistil); and the glumes are similar to those of the normal florets. A proliferated spikelet is illustrated in Fig. 1, and the details of its structure are given below in the description of the variety.

THE BULBLETS IN *POA BULBOSA*

Some pertinent literature on basal swellings in plants has been reviewed by Geiger (29) and by Evans (27). The grasses termed "bulbous" (*Melica bulbosa, Arrhenatherum elatius* var. *bulbosa*, etc.) have, in reality, corms rather than bulbs at the base, corms being solid thickened internodes with no leaves surrounding them. A variant of a corm occurring in *Phleum pratense* is designated a "haplocorm" by Evans (27). In *Poa bulbosa*, however, the basal swelling is not solid, or corm-like, but contains several loose leaves resembling the scales of an onion, and is therefore truly bulbous. *Poa bulbosa* is the only known grass which possesses true bulbs, as its common name, bulbous bluegrass, indicates.

Sowerby (14) states that *Poa bulbosa* is "well distinguished by its bulbs, which, late in summer, when the leaves are withered, become detached from the soil in tufts, which are carried about by the wind." Such dissemination of the bulblets ("bulbs") is not mentioned by any other author nor has it been observed by the writer.

The bulblet is characteristic of both the species and the variety. It is further treated in the description of the species below.

STUDY OF SPECIMENS

The majority of the author's collections of the proliferated form were made in the Pacific Northwest, either from agricultural fields or under conditions of escape from cultivation. These specimens, in comparison with the normal form previously reported (31) and with the remainder of the proliferated material reported herein, show, in general, an increase in the number and size of several structures, *e. g.*, height and diameter of culm; number of nodes; and length of roots, sheaths, blades, ligule, panicle, and panicle-branches. The original collections are in the herbarium of the Division of Botany, College of Agriculture, Davis, California, and duplicates have been deposited in the herbaria of the University of California at Berkeley, the California Academy of Sciences at San Francisco, and the U. S. National Herbarium at Washington, D. C.

The present study included a detailed examination of approximately 75 specimens from the following countries: Armenia, Austria, Belgium, Canada, Esthonia, France, Germany, Hungary, India, Latvia, Russia, Sweden, Switzerland, Syria, Turkey, and the United States (states of California, Idaho, North Carolina, North Dakota, Oregon, and Washington). A few of the specimens inspected are worthy of special note. The earliest ones seen by the writer are the collection in 1807 by Persoon at Paris (U. S. National Herbarium 749263) and that by Wilhelm Suksdorf, in May, 1809, in an alfalfa field in Bingen, Washington, U. S. A. (University of California 351715 and U. S. National Herbarium 1435204). An elevation of "10,000±" is indicated for a specimen (University of California 322660) collected by R. R. Stewart (7142) on Mt. Mahadeo, India, June 7-8, 1922; and an altitude of 3,350-3,900 meters is mentioned for two specimens (University of California 282885 and 282886) collected by R. C. Ching (691 and 693) in La Che Tze mountains,

south of Sining, Kansu, China, August 3, 1923. The first observation of this form in California was made in 1919 by P. B. Kennedy and B. A. Madson, in an old alfalfa field near Escalon. This grass was collected by the present author (Halperin 304 and 323) with *Juncus patens* on overflow land and with *Vicia villosa* on burned-over, rocky land in northern California, in May, 1930, and April, 1931, respectively.

CONCLUSION

The description given below is based on the species description (31) modified here to include several variations presented by the proliferated material inspected for the present study.

The following description of the variety is offered as the most comprehensive and definite for the existing knowledge of that form.

POA BULBOSA L.

Habit erect, perennial, bunchy-tufted or sod-forming, 10–75 cm high; *roots* 5–20 from each bulblet, 1–10 cm long, filiform with numerous rootlets about 1 mm long; *bulblets* basal on the culm, about 0.5 cm long, solid, with scarious, or papery, prominently-veined, brown scales, the inner ones often tinged with purple; *culm* one, terete, hollow, geniculate when mature at the lowermost node or occasionally at the lower two nodes, gray-green often tinged with purple, 1–2 mm wide at the base, grooved or at least noticeably veined, glabrous or occasionally scaberulous; *nodes* two or three (rarely four), the lower two located (except very rarely) within the lowest third of the culm, in mature material purple or occasionally brown, thickened or sometimes forming a groove in the culm; *leaves* extending two-thirds of the height of the culm, seldom higher; *sheaths* nearly or entirely enveloping the culm, prominently ridged, puberulent or scaberulous, less frequently glabrous, those of the basal leaves 1–5 cm long and usually purple or purple-tinged, those of the flowering culm 5–10 cm long and gray-green often tinged with purple or (when mature) yellow; *blades* scaberulous or puberulent or sometimes glabrous, those of the basal leaves 2–8 cm long, those of the flowering culm 2–10 cm long; *ligule* white, hyaline, 1–5 mm long, semicircular to oblong-acuminate, the margins entire, erose-dentate, uniformly toothed or irregularly serrate, or even lobed; *panicle* ovoid to oblong, usually drooping and one-sided but often erect and symmetrical, 1.5–10 cm long; *panicle-branches* when present, 3–13 mm long, capillary, puberulent (or seldom glabrous), in two's or three's but the group lowermost in the panicle usually in four's or five's; *pedicels* 1–3 mm long, puberulent (or seldom glabrous); *spikelets* sessile or pedicellate, ovate-oblong, 4–6 mm long; *florets* 3–6 (rarely more); *glumes*, the first 2.5–3 mm long, the second 3–4 mm long, each with a prominent scabrous keel and with two lateral nerves, occasionally wanting in the first glume; *lemma* 3 mm long, oblong-lanceolate, scarious, membraneous on the upper margins, acute, with a prominent keel nearly always silky-hairy, and with two pairs of lateral nerves, ocasionally faint; *palea* 2.5 mm long, with its two keels scabrous and produced into two teeth; *stamens* three, 1–1.5 mm long, yellow; *pistil* with a green or reddish-brown round ovary 1 mm long and with two white, feathery stigmas 1 mm long; *caryopsis* wanting.

var. *vivipara* Koel.—*Spikelet* consisting of a bulbil, lemmas, and glumes; *bulbil* usually 8–10 mm long, purple (occasionally brown), one in each spikelet and inclosed by the terminal lemma; *lemmas*, the terminal one elongated to 1 or even 2 cm, often showing a ligule, the two others 4–6 mm long, glabrous, the five nerves generally quite prominent in all the lemmas; *glumes* in ripe material usually horizontally divergent; *palea*, *stamens*, and *pistils* wanting.

The proliferated material shows, in general, a greater variation than the normal. Examples are nodal geniculation and the character of the ligule, which are illustrated in Figs. 2 and 3.

SUMMARY

The swelling at the base of the culm in *Poa bulbosa*, both in the species and in the variety, consists of a thickened solid internode surrounded by scale-like leaves. This grass is, as far as known, the only member of Gramineae (Poaceae) which possesses true bulbs. Other grasses, commonly designated as "bulbous," have corms rather than bulbs.

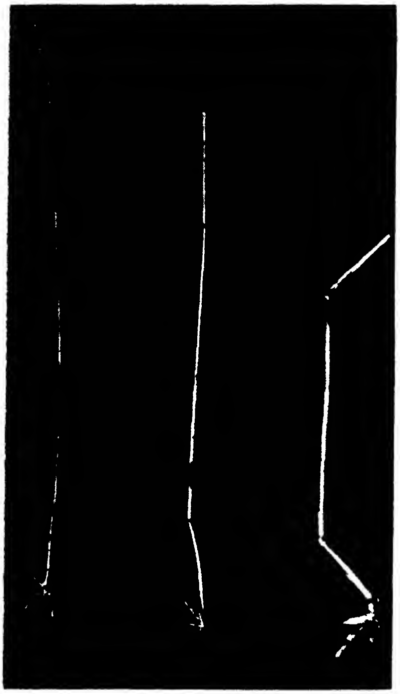

FIG. 2.—Nodal geniculation. *Left*, no geniculation at either node; *center*, geniculation at first (lowermost) node, in the typical case; *right*, geniculation at both nodes.

This grass is either bunchy-tufted or sod-forming. The culm is typically geniculate at the lowermost node. The basal third of the culm contains the two (lowermost) nodes. The sheaths and blades on the flowering culm are longer than those in the basal leaves. The ligule is of special interest for its diversity of shape and of margination. The panicle, at least in mature material, is secund (one-sided). In the proliferated form, the palea, stamens, and pistils are wanting.

The valid name for the proliferated form of bulbous bluegrass, variously designated in the literature, is *Poa bulbosa* L. var. *vivipara* Koeler. This name is applied to specimens in which all the florets are proliferated. Material containing any normal florets whatever is referred to the species.

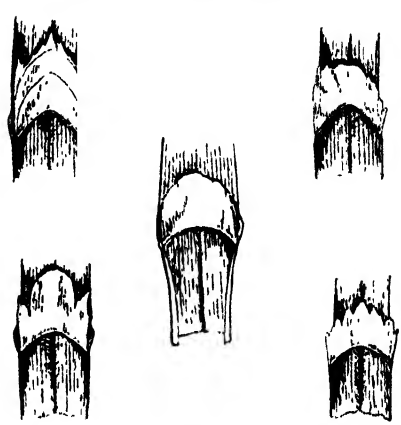

FIG. 3.—Ligule, showing only a few of the variations.

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ELECTRODIALYSIS COMPARED WITH THE NEUBAUER METHOD FOR DETERMINING MINERAL NUTRIENT DEFICIENCIES IN SOILS[1]

P. H. Brewer and R. B. Rankin[2]

In the literature are found several papers relative to the use of electrodialysis for extracting a portion of the cations from the soil solution. To mention only a few of these, one might refer to the work of Bradfield (1),[3] Clark, Humfield, and Albens (2), Mattson (3), and Löddesol (4). The greater part of the work has been done to determine the total amount of electrodialyzable bases in the soil solution without subsequent determination of the amounts of the individual cations so extracted.

McGeorge (9), on the other hand, has reported that the process of electrodialysis is an excellent means of dissolving the active or available forms of phosphate from calcareous soils. The apparatus used by McGeorge was essentially that of Mattson, parchment paper being used as membranes at both cathode and anode. The somewhat similar three-chamber Bradfield cell was used in the work reported in this paper, although the anode membrane of parchment paper was replaced by one of collodion impregnated with hemoglobin, as described by Bradfield and Bradfield (5).

Since the Neubauer method for determining amounts of available phosphorus and potassium which soils contain, as described by Thornton (6), has come to be favorably regarded by certain workers, it was proposed to compare results secured by the Neubauer method upon certain soils with those secured by limited electrodialysis upon the same soils.

APPARATUS

Two Bradfield electrical dialyzers coupled in parallel (Fig. 1), were used in the determinations reported in this paper. The cathode membranes were parchment, while the anode membranes were collodion impregnated with hemoglobin. The soil in the middle chamber was kept in suspension by constant stirring. Preliminary work by the senior author had indicated that, in order to recover from a soil suspension an amount of cations closely approximating that available to plants, the soil should be subjected to electrodialysis for a period of 6 hours, using a direct current of 110 volts with an amperage of 3 to 5 milliamperes. Accordingly, the course dictated by these findings was adhered to, although previous trials with the hemoglobin-impregnated anode membrane had not been carried out. The dialysate was removed from the anode chamber, and the chamber refilled with water once each hour. The water supply was renewed at practically the same rate in the cathode chamber by means of inflow at the bottom and overflow at the top of the chamber.

[1]Contribution from the Department of Agronomy, Purdue University, Lafayette, Indiana. Received for publication November 10, 1932.

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[3]Reference by number is to "Literature Cited," p. 417.

Both dialysates were preserved and evaporated on the steam bath for analysis. In the Bradfield cell, 50 grams of the heavier soils may be subjected to dialysis, while it is scarcely advisable to use more than 20 grams of the muck soils.

FIG 1.—Assembled apparatus for electrodialysis of soils.

CHEMICAL METHODS

In determining the potassium in the cathode dialysate and the phosphorus in the anode dialysate, the methods used were essentially those of the Association of Official Agricultural Chemists (7). Since the amounts of phosphorus recovered were quite small in many cases, it was found advisable to evaporate the anode dialysate to dryness after the addition of a few drops of nitric acid, and then heat in the muffle furnace for 10 minutes to burn out all organic matter. The residue was then taken up with hydrochloric acid and the determination completed. In the determination of potassium, the treatment with ammonium oxalate, subsequent to precipitation with ammonium carbonate, was found to be necessary.

SOILS STUDIED

The soils used in this work were those on which Naubauer values had previously been determined by Thornton, Indiana Chemist's Department, although these values were not known by the authors until the results of the electrodialyses were recorded. Dialyses were made in duplicate upon each soil and these duplicates carried through to final determinations. The agreement of these duplicates, although coming from different cells, was very satisfactory in practically all cases and particularly in the potassium determinations.

EXPERIMENTAL RESULTS

Twenty-three widely varable soils were subjected to electrodialysis as outlined above. The average results of the determinations of P_2O_5

and K_2O in the duplicate dialysates of each soil are shown in Table 1 in comparison with results secured by the Naubauer method upon the same soils.

TABLE 1.—*Available P_2O_5 and K_2O in milligrams per 100 grams of soil according to electrodialysis as compared with the Neubauer method.*

Soil No.	Soil type and treatment	pH	P_2O_5		K_2O	
			Neubauer*	Electrodialysis	Neubauer*	Electrodialysis
1	Bedford, Ind., silt loam; lime alone	6.9	1.4	0.9	6.4	5.4
2	California citrus soil, dry region, sandy loam	8.4	4.5	5.9	38.7	34.8
3	Rensselaer, Ind., calcareous black sandy loam (bogus spot).. ...	8.0	2.1	3.7	1.4	6.0
4	N. Vernon, Ind., Clermont silt loam; no treatment...........	5.4	1.6	0.9	0.9	5.4
5	Iowa muck; potato soil	7.4	3.9	9.0	21.3	21.9
6	Iowa muck; potato soil	6.9	15.0	18.6	52.8	55.2
7	Iowa muck, potato soil	6.5	3.0	12.3	43.2	15.2
8	Iowa muck, potato soil	6.4	5.1	16.2	14.4	18.6
9	Calcareous Iowa silt loam; no treatment. (bogus spot)	8.0	3.8	2.8	0.6	3.6
10	Same as No. 9, plus 500 pounds muriate of potash per acre	8.2	3.7	2.6	13.3	10.4
11	Same as No. 9, plus 1,000 pounds muriate of potash per acre	8.1	5.2	5.1	18.8	15.6
12	Wisconsin silt loam; fallowed, not limed	5.7	5.3	1.9	13.3	10.8
13	Same as No. 12, plus lime	6.4	4.7	1.6	4.2	6.0
14	Virgin Illinois soil, one year from sod; black silt loam	5.9	1.6	2.3	11.5	11.5
15	Missouri silt loam	6.2	8.5	7.4	27.8	26.4
16	California citrus soil similar to No. 2 except in reaction	6.4	14.2	6.0	40.0	15.6
17	Norfolk fine sandy loam, Texas	5.5	0.8	0.7	4.8	11.1
18	Similar to No. 17.	5.2	0.9	0.6	1.2	3.6
19	Missouri, probably similar to No. 15	6.4	26.0	11.8	47.2	51.6
20	Clermont silt loam, lime, manure nitrogen, potash. 1 ton rock phosphate 9 years and 1 ton rock phosphate 3 years before sampling	6.1	1.6	0.8	0.5	2.4
21	Same as No. 20, except ½ ton 16% superphosphate instead of rock phosphate	6.1	1.6	0.7	1.0	2.2
22	Culver sand, lime, manure; 1 ton rock phosphate 6 years before sampling	6.0	1.7	1.0	0.0	2.4
23	Same as No. 22 except ½ ton 16% superphosphate instead of rock phosphate	6.0	1.9	0.9	0.0	2.4

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DISCUSSION

Thornton has suggested 4 mgms P_2O_5 and 10 mgms K_2O as tentative limit values for deficiencies with the Naubauer method as ap-

plied to average field crops under Indiana farming conditions. Table 1 reveals that, with the exception of soil No. 17, the K_2O values secured by electrodialysis and the Naubauer method are either both below or both above this limit. This table also shows that, with the exception of soils Nos. 5, 7, 12, and 13, the P_2O_5 values secured by the two methods are either both above or both below the limit value.

The detection of additions of potash to soil No. 9, as represented by Nos. 10 and 11, by both the Naubauer method and electrodialysis, is of particular interest. The depression of recoverable K_2O due to liming as shown by both methods in soil No. 13, which is the same as No. 12 except that lime has been added, is also of special interest.

Thornton (6) cites several instances, in which extremely high phosphate results are secured by both 0.2 N nitric acid extractions and the Illinois phosphate test described by Bray (8), when these methods are used on soils which have received applications of phosphate rock. Results secured by the Neubauer method on such soils agree more closely with pot and field plat yields. It is of interest to note that closely similar results are secured by electrodialysis and the Neubauer method upon soils Nos. 20 and 21 and soils Nos. 22 and 23, although Nos. 20 and 22 have received heavy applications of phsophate rock, while Nos. 21 and 23 have received heavy applications of superphosphate.

One feature which commends the electrodialysis method is the relatively short time from the beginning of the dialysis until the determinations may be completed. Such period need not exceed 8 hours for the P_2O_5 determinations or 12 hours for the K_2O determination.

The similarity of the amounts of potassium and phosphorus extracted by the two Bradfield cells when operating upon equal quantities of the same soil was in most cases quite remarkable. This was particularly true of potassium. The greatest variation in K_2O between any two duplicate dialysates was 3.0 mgms, while the majority varied less than 1 mgm of K_2O.

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AVAILABILITY TO CORN OF NUTRIENTS IN THE A_2 AND B HORIZONS OF HILLSDALE LOAM[1]

C. E. MILLAR[2]

The ability of corn, oats, barley, and potatoes to utilize soluble nutrients occurring in the lower soil horizons was shown by Weaver, Jean, and Crist (1).[3] Millar (2) showed that while corn can absorb soluble nutrients placed in the lower horizons, under the conditions of his experiments insufficient quantities of nutrients were obtained from unfertilized soil of the A_2 and B horizons of Coloma sand and Leslie (now named Hillsdale) sandy loam to make possible any considerable growth. The addition of NH_4NO_3 increased growth to a slight extent in the B horizon and more appreciably in the A_2 horizon. That crops vary in their ability to grow in different horizons of various soil profiles was shown by Millar (3). The question arises as to whether the failure of a given crop to grow satisfactorily in material from a lower horizon of a certain soil profile is due to a lack of available nutrients or to some other condition, as soil reaction, the presence of a toxic substance, or an undesirable physical condition.

EXPERIMENTAL

To determine to what extent the addition of soluble nutrients will overcome the non-productiveness of the A_2 and B horizons of Hillsdale sandy loam for corn, glazed tile 10 inches in diameter and 24 inches long, set with the upper edge slightly above the surface of the soil, were filled with soil from the different horizons as indicated in Table 1 and planted to corn. The experiment was started in June, 1924, and no other additions were made to the soil that year except to that in nine of the tiles where 0.528 gram of NH_4NO_3 was added to each. The results for 1924 were reported previously (2) and were referred to briefly earlier in this paper.

On May 17, 1925, about ¼ inch of soil from the surface of each tile was scraped off in order to remove any foreign material which might influence the plant growth. The soil to a depth of 4 inches was then removed, pulverized, the roots removed, and the soil replaced, after fertilizers as shown in Table 1 had been added to the soil in the tiles. The fertilizer was in solution and was prepared from C. P. H_3PO_4, $NaNO_3$, and K_2SO_4. The rates of application were equivalent to 500 pounds per acre of 16% superphosphate, 300 pounds per acre of $NaNO_3$, and 200 pounds per acre of sulfate of potash. Calculations were based on the area of the soil surface in the tile. Corn was planted at once and thinned to two plants per tile when a few inches high. On September 26 the corn was cut, taken to the laboratory, and weighed when it became thoroughly room dry.

Due to the dryness of the season the growth was limited in all

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Journal Article No. 128 (n.s.). Received for publication November 14, 1932.

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[3]Reference by number is to "Literature Cited," p. 426.

cases but not sufficiently to obliterate the influence of the fertilizers, as can be observed from the data.

In 1926, corn was again planted after taking the precaution to remove the surface ¼ inch of soil and to repeat the fertilizer treatments as described for 1925. During the dry portion of the seasons the corn was watered several times using distilled water in quantities varying from 1,000 to 2,000 cc for each tile, according to the size of the plants. The corn was cut, brought to the laboratory, and weighed when room dry. The data are presented in Table 1.

TABLE 1.—*Weights of plant tissue grown on soil from different horizons contained in 10-inch tile and fertilized as indicated.*

Soil horizon	Nutrients added in pounds per acre	Grams of air-dry plant tissue*		
		1925	1926	1928
Surface†	None	59.35	51.40	33.40
Surface	N, 48 P_2O_5, 80 K_2O, 108	47.35	38.35	30.60
A_2	None	7.25	9.10	8.80
A_2	N, 48 P_2O_5, 80	15.95	17.35	12.55
A_2	N, 48 P_2O_5, 80 K_2O, 108	23.10	15.15	11.70
B	None	12.25	7.85	2.75
B	N, 48 P_2O_5, 80	17.70	17.50	11.00
B	N, 48 P_2O_5, 80 K_2O, 108	20.35	13.70	11.70‖
A_2+B+8 in. of surface‡	None	47.45	22.80	13.95
of surface	N, 48 P_2O_5, 80	36.45	32.95	23.80
of surface	N, 48 P_2O_5, 80 K_2O, 108	63.25	36.85	32.95
A_2+B+8 in. of surface soil below§	None	40.20	29.25	6.9
of surface soil below§	N, 48 P_2O_5, 80 K_2O, 108	43.75	23.50	20.45

*Average from two tile unless otherwise specified.
†Tile were filled entirely with surface or plow soil.
‡Tile were filled to within 8 inches of the top with a mixture of soil from the A_2 and B horizons and the filling completed with surface soil.
§The holes for the tile were dug about 31 inches deep and 8 inches of surface soil put in the bottom before placing the tile, which were then filled with a mixture of soil from the A_2 and B horizons. ‖Material from one tile only.

In 1927, the surface ¼ inch of soil was discarded from each tile in order to remove any foreign material which accumulated during the winter. Oats were seeded April 15. Early growth was satisfactory, the oats in the tile containing surface soil growing much more rapidly than those in the tile containing soil from the lower horizons. Insect damage to the plants in several tile rendered yields unreliable, and hence they are not reported.

Oats were again seeded in 1928 after removing a ¼ inch layer of soil and giving each fertilized culture a double application of nutrients. Due to cold wet weather, germination and early growth were unsatisfactory so the oats were removed and corn planted on May 20.

The data from the tile filled entirely with surface soil show that the application of a complete fertilizer was followed each year by a lower yield than was obtained from the unfertilized soil. In all but the first year a fertilizer containing N+P increased the yield in the tile containing 8 inches of surface soil on top of a mixture of soil from the A_2 and B horizons. Each year a complete fertilizer gave a larger yield in these tiles than a fertilizer containing N+P only.

The yields from tile filled completely with surface soil but receiving no fertilizer were considerably larger each year than those from tile containing only 8 inches of unfertilized surface soil. The yields from the tile filled entirely with surface soil and receiving complete fertilizer and those containing 8 inches of surface soil and receiving complete fertilizer were virtually the same except in 1925. This result indicates that the high producing power of the former was due mainly to the additional plant food available rather than to an increased moisture-holding capacity or a more suitable physical condition.

When 8 inches of surface soil were placed below the tile filled with a mixture of soil from the A_2 and B horizons, the yields were not greatly influenced the first 2 years by the application of a complete fertilizer. The third year, however, the fertilized soil yielded virtually three times as much as the unfertilized. These data give further evidence of the ability of the lower roots to absorb available nutrients. The increased yields from tile with 8 inches of surface soil below the mixture of A_2+B soil over those from tile, filled completely with soil from the A_2 and B horizons, no fertilizer being used in either case, furnishes additional evidence on this point.

A comparison of the yields for 1925 and 1926 from the tile having 8 inches of surface soil on top of a mixture of soil from the A and B horizons and from the tile having 8 inches of surface soil below the mixture of soil from the A and B horizons, no fertilizer being applied, indicates that for corn it does not make a great deal of difference whether the surface soil is on the top or at a depth of 2 feet. The third year the tile with surface soil on top gave decidedly larger yields.

The results in Table 1 show that the growth in tile containing either 8 inches of surface soil on top of a mixture of soil from the A_2 and B horizons, or entirely filled with it, was superior to the growth in tile containing only soil from the A_2 or B horizons. In no case did an application of nutrients induce a growth on soil from the A_2 or B horizons equal to that from tile containing surface soil.

The yields for 1925 indicate that soil from both the A and B horizons is in need of a complete fertilizer, while the data for 1926 show no great advantage resulting from the addition of K to a combination of N and P.

FIG. 1.—Influence of nutrients on growth of corn in soil from the A_2 horizon. 1, check; 2, nitrogen; 3, phosphorus; 4, nitrogen and phosphorus; 5, nitrogen, phosphorus, and potassium.

FIG. 2.—Influence of nutrients on growth of corn in soil from the B horizon. 1, check; 2, nitrogen; 3, phosphorus; 4, nitrogen and phosphorus; 5, nitrogen, phosphorus, and potassium.

The failure of fertilizer applications to put the yielding power of the A and B horizons on a par with that of the surface soil may be due to (a) a difference in water-retaining capacity; (b) the lack of some element other than N, P, or K; (c) a fixing power of the soil for one or more of the nutrients supplied, sufficient to render the application inadequate; (d) the presence of some toxic substance; and (e) an unsatisfactory physical condition. It is noteworthy that the yields did not increase from the first to the last year of the test

which would indicate that if a toxic substance were responsible for the depressed growth its influence did not decrease as the result of exposure of the soil to weathering action. (See Figs. 1, 2, and 3.)

GREENHOUSE TRIALS

In order to have moisture and other conditions under better control, soil was removed from a number of the tile in the fall of 1928, screened, and placed in 2-gallon glazed jars in the greenhouse. The soil horizons used and the fertilizer applications employed are given in Table 2. The rates of fertilizer applications, calculated on the area of the 10 inch tile from which the soil was taken, were H_3PO_4 sufficient to equal 1,000 pounds per acre of 16% superphosphate, 600 pounds per acre of C. P. $NaNO_3$, and 400 pounds per acre of C. P. K_2SO_4.

FIG. 3.—Comparison of growth of corn on (1) soil from B horizon, (2) surface soil, (3) soil from A_2 horizon, all receiving complete fertilizer.

The solutions containing the nutrients were mixed through the soil thoroughly and enough additional water added to bring the soil to a suitable moisture content for plant growth.

About 3 weeks after planting, the corn on the soil from the A_2 and B horizons was not making a satisfactory growth. Tests for water-soluble phosphorus by Spurway's method (4) gave negative results. An additional quantity of H_3PO_4 solution equivalent to 500 pounds per acre of 16% superphosphate was added to all jars originally receiving P. After 2 weeks no particular improvement was noted, although tests showed the presence of nitrates and traces of soluble P in those jars receiving P applications. The original applications of $NaNO_3$ and K_2SO_4 were repeated on the A_2 and B cultures and 1 week later another 500 pounds per acre of 16% superphosphate equivalent were added. By the end of another week the plants in the A_2 and B horizons were showing a dark green color and growing satisfactorily. The corn was cut when in tassel, room dried, and weighed.

The soil was screened to remove roots and replaced in the jars. Tests for water-soluble phosphorus showed about 1 p.p.m. in each soil to which phosphoric acid had been added. Soluble nitrates were found in all soils regardless of whether $NaNO_3$ had been supplied. In consideration of the quantities of nutrients already applied and the positive tests for NO_3 and water-soluble P, no further additions of fertilizer salts were made. Corn was planted and again harvested when in tassel. Weights of room-dry plants are given in Table 2.

The yields for the first crop in 1929–30 show that by fertilization and with adequate water corn grew as well on the soil from the A_2 and B horizons as on the unfertilized surface soil. When complete fertili-

TABLE 2.—*Weights of plant tissue grown on soil from different horizons contained in jars in the greenhouse and fertilized as indicated.*

Soil horizon	1929-1930			1931	
	Nutrients in pounds per acre	Grams of air-dry plant tissue*		Nutrients in pounds per acre	Grams of air-dry plant tissue*
		1st crop	2nd crop		
Surface	None	23.60	9.15	None	39.50
Surface	N, 96 P_2O_5, 160 K_2O, 216	43.45	7.75	N, 192 P_2O_5, 320 K_2O, 432	54.70
A	None	5.70	2.95	None	10.30
A	———	———	———	N, 192	11.30
A	———	———	———	P_2O_5, 320	23.60
A	N, 96 P_2O_5, 160	22.00	9.80	N, 192 P_2O_5, 320	31.00
A	N, 96 P_2O_5, 160 K_2O, 216	23.95	12.50	N, 192 P_2O_5, 320 K_2O, 432	36.30
A 50% Sand 50%	———	———	———	None	6.60†
Sand 50%	———	———	———	N, 192 P_2O_5, 320 K_2O, 432	45.70†
B	None	5.25	1.80	None	2.20
B	———	———	———	N, 192	1.80
B	———	———	———	P_2O_5, 320	10.70
B	N, 96 P_2O_5, 160	12.90	14.75	N, 192 P_2O_5, 320	38.80
B	N, 96 P_2O_5, 160 K_2O, 216	22.00	12.00	N, 192 P_2O_5, 320 K_2O, 432	34.90
B 50% Sand 50%	———	———	———	None	21.50†
Sand 50%	———	———	———	N, 192 P_2O_5, 320 K_2O, 432	42.90†

*Average weight from two jars unless otherwise specified.
†Results from one jar only.

zer was added, however, the growth was approximately twice as great on the surface soil as on the soil from the A_2 or B horizons. Potassium did not appear to be a limiting element for plant growth on the A_2 horizon which agrees with the field results for 1926 and 1928. On

the other hand, K materially increased the growth on the B horizon which is at variance with the field results.

The second crop was planted because of the marked increase in growth following the final application of nutrients to the first crop. In consideration of the total quantity of nutrients added it would seem that there should have been ample for the growth of a second crop. The yields for the second crop, however, are much less than for the first with one exception. The small growth may be attributed in part to the high temperatures in the greenhouse during the period of growth as the corn was not planted until June 6. The data for the second crop on the A_2 soil agree reasonably well with previous results. On the B horizon soil potassium did not increase growth which result agrees with field results but is at variance with results for the first crop in the greenhouse. The yields for both the fertilized and unfertilized surface soil were lower than for the fertilized A_2 and B soil. It should be remembered in this connection that the unfertilized surface soil had already produced four crops of corn and one of oats, and that with the exception of 500 pounds of superphosphate, the additional applications of nutrients given the soil from the A_2 and B horizons during the growth of the first crop were not supplied to the surface soil.

In the fall of 1930, fresh soil was taken from the field, screened, and potted in 2-gallon jars. Nutrients were added in quantities equal to the total amounts supplied to the jars in the experiment just described; that is, 1,200 pounds of $NaNO_3$, 2,000 pounds of 16% superphosphate equivalent, and 800 pounds of K_2SO_4.

In order to determine if the physical condition of the soil was responsible to an appreciable extent for the inferior growth of corn in soil from the A_2 and B horizons, an equal quantity by weight of quartz sand was mixed with the soil and two jars filled with the mixture. To one jar was added complete fertilizer, while the other received no fertilizer.

It is noteworthy that complete fertilizer materially increased the yield produced on surface soil.

Nitrogen increased the yield on soil from the A_2 horizon very slightly, phosphorus more than doubled the yield of the unfertilized soil, while a combination of nitrogen and phosphorus trebled the yield. The yield from complete fertilizer was about 17% better than from the N+P treatment, indicating only a slight response to K.

In the case of soil from the B horizon the addition of nitrogen decreased the yield slightly, while addition of phosphorus increased it almost 5 times. Phosphorus and nitrogen used jointly gave a yield approximately 17 times as great as that obtained from the untreated soil, but when potassium was also included in the fertilizer the yield fell to about 16 times that of the unfertilized soil. From these data it appears that available nitrogen and phosphorus are very deficient in the soil from both the A_2 and B horizons but that potash is present in adequate quantities in the B horizon and for corn under the conditions of the experiment is only slightly deficient in the A_2 horizon. The addition of a complete fertilizer to soil from the A_2 or B horizons and of P+N to that from the B horizon gave yields commensurate

with the yield of the unfertilized surface soil but decidedly less than that from the fertilized surface soil.

The addition of an equal quantity of sand to soil from the A_2 horizon resulted in a smaller yield than was obtained from the soil alone. The addition of complete fertilizer to the mixture gave a yield considerably in excess of that obtained when complete fertilizer was added to the soil without admixture of sand. The results suggest that addition of sand improves the condition of the soil for the growth of corn from a physical standpoint but by dilution reduces the quantity of nutrients available for plant growth. Soil from the B horizon mixed with an equal weight of quartz sand produced almost 10 times as much corn as the soil unmixed with sand. When complete fertilizer was added to the soil-sand mixture the yield was much higher than when the fertilizer was added to the soil alone. The data indicate that the soil from the B horizon is considerably improved as a medium for the growth of corn by the addition of an equal weight of sand. (See Figs. 4 and 5.)

FIG. 4.—Effect of addition of sand and also of fertilizer on growth of corn in soil from the B horizon. 1, no addition; 2, ½ soil + ½ sand; 3, ½ soil + ½ sand + complete fertilizer.

DISCUSSION AND CONCLUSIONS

The data from trials under field conditions show that material from the A_2 horizon of the soil studied is very unproductive for the growth of corn. The addition of soluble nitrogen and phosphorus greatly increased the growth of corn, while potassium in addition to nitrogen and phosphorus contributed but little to the growth of the plants.

FIG. 5.—Effect of addition of sand and also of fertilizer on growth of corn in soil from the A_2 horizon. 1, ½ soil + ½ sand; 2, no addition; 3, ½ soil + ½ sand + complete fertilizer.

The results of tests with the material from the B horizon are similar to those with material from the A_2 horizon.

With the addition of moderate quantities of nutrients the yields on soil from the A_2 and B horizons were much inferior to those produced in tile containing 8 inches of surface soil on top of a mixture of material from the A_2 and B horizons.

On the whole, corn grew as well in tile having 8 inches of surface soil under 2 feet of mixed soil from the A_2 and B horizons as in tile having 8 inches of surface soil on top of mixed soil from the A_2 and B horizons, again demonstrating the ability of the lower root system of corn to absorb available nutrients when present.

In the greenhouse the soil from the A_2 and B horizons showed a great response in plant growth to the addition of phosphorus alone and little increase from the addition of nitrogen alone. A combination of nitrogen and phosphorus gave very large increases which were not appreciably augmented by the addition of potassium.

Results obtained when 50% of quartz sand was added to soil from the A_2 and B horizons indicate that a poor physical condition may tend to depress the growth of corn in soil from the A_2 and B horizons.

In general, the data indicate that the inferior growth of corn in soil from the A and B horizons of the soil studied is due very largely to a lack of available nutrients and that very large quantities, particularly of phosphorus, must be added to satisfy the adsorptive capacity of the soil and make plant growth commensurate with that obtained when surface soil is used.

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NOTE

A THREE-ROW NURSERY PLANTER FOR SPACE AND DRILL PLANTING[1]

A three-row nursery planter that will sow one row or three rows, as desired, and space-plant wheat kernels at various intervals or drill them at various rates has been constructed at the Washington Agricultural Experiment Station. A feature of this planter is that it will seed to the last few kernels and that nearly as many rows of wheat can be space planted as drilled within a given period.

The planter, as shown in Fig. 1, is a modified Wright garden planter to which have been added two planter sections, each having a furrow opener, a feed spout, and a packer wheel. The frames of the two added sections were constructed of ¾-inch pipe fittings, and the furrow openers and packer wheels were purchased from the manufacturer. The added sections are attached to the center planter by

[1]Scientific Paper No. 253, College of Agriculture and Experiment Station, State College of Washington, Pullman, Wash. The writer is indebted to the Department of Agricultural Engineering, State College of Washington, for the use of shop equipment, and to C. C. Johnson, assistant professor of agricultural engineering, and P. C. McGrew, agricultural engineer, Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, for helpful suggestions.

sliding bolts and compression springs so as to allow considerable flexibility for use on rough or uneven seedbeds and are set to seed the rows 1 foot apart.

The seed box of the planter is raised 13.5 inches and two additional outlets are cut into its base. This box is attached to a wide hinge so that it may be easily emptied into a removable pan. A shut-off placed between the base of the seed box and the hinge wing is kept in closed position by a spring until opened by a grip lever on one of the handles.

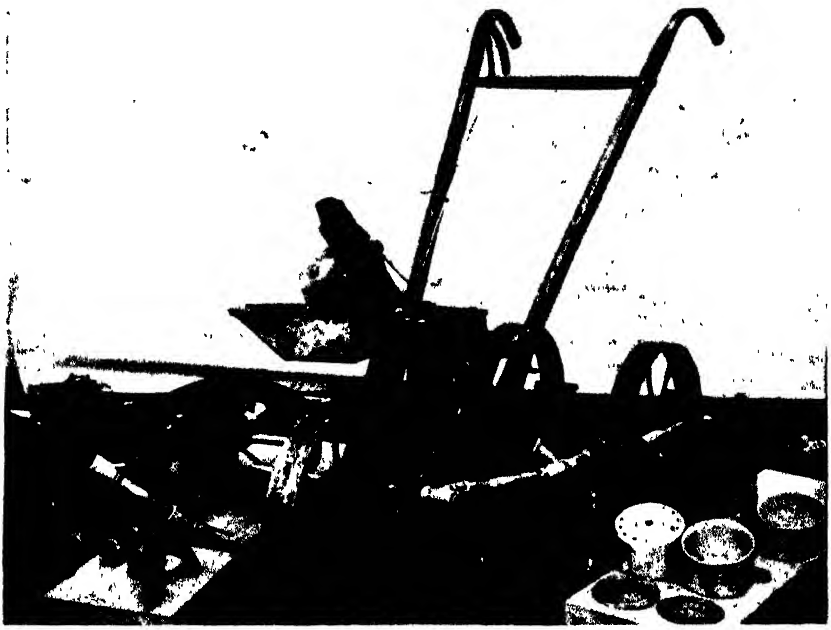

FIG. 1.—Three-row planter showing seed box, special seed cups, and one planter section detached

The regular set of seed discs or plates is supplemented by special seed cups, each having a conical or high-center bottom which causes the seed to gravitate outward. As the seed cup turns, horsehair brushes attached to the top inner wall of the seed-box hopper sweep the grain into the cup slots, remove the surplus, and force the seed from the filled slots into the outlets. A hopper with brushes attached is shown beside seed plate 2.

The seeding rate of the cup plates depends upon the number and size of the seed slots and the sprocket combination of the drive system. The plates marked 1 will space wheat either 1½ or 3 inches apart, depending upon which of the two sprockets on the front wheel is used. The plate marked 2, when used with the larger sprocket, will seed approximately 12 grams per 16-foot row. In a series of seeding tests the number of kernels of wheat dropped for each revolution of the plate marked 1 ranged, in nearly every case, from 13 to 15

for plump or slightly shriveled seed of varieties of the Crimean type, from 10 to 14 for very long seed such as that of Baart or very plump seed such as that of Fortyfold selection 54, and from 14 to 17 for varieties with shorter seed, if plump, but as many as 21 if badly shriveled. During these tests it was noted that the rate of seeding was influenced less by the speed of the planter when plates 1 and 2 were used than when the original disc plates were used.

The capacity of the planter has not been definitely determined. However, on the cold morning of October 17, 1932, 237 three-row plats, each 18.5 feet long, were drilled in 95 minutes by a crew of four men, one pushing, one pulling, and two changing varieties.

Photographs showing detailed construction of the seed box, seed plates, and planter attachments are available to persons interested.—O. A. Vogel, *Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, Pullman, Wash.*

AGRONOMIC AFFAIRS

PROGRAM OF THE SOILS SECTION

Programs are being planned in each of the fields listed below for the meeting of the Soils Section of the Society in Chicago, in November. The names of those in charge of these divisional programs are also listed. Anyone having papers to submit for consideration are requested to communicate directly with the Chairman of the Division before which he would prefer to present the paper, giving its title, the length of time desired for presenting it, and a brief statement regarding its contents. Abstracts of papers will not be printed. To be assured of consideration, papers must be submitted before October 1.

Division 1. Soil Physics and Chemistry—*Chairman*, Dr. H. G. Byers, Bureau of Chemistry & Soils, U. S. Dept. of Agr., Washington, D.C.

Division 2. Soil Biology—*Chairman*, Dr. E. B. Fred, Dept. of Bacteriology, University of Wisconsin, Madison, Wis.

Division 3. Soil Fertility—*Chairman*, Dr. C. E. Millar, Division of Soils, Michigan State College, East Lansing, Mich.

In addition to the above a few joint sessions will be held with the American Soil Survey Association. Papers dealing primarily with soil morphology should be submitted to the President of the American Soil Survey Association, Prof. M. F. Morgan, Dept. of Agronomy, Agricultural Experiment Station, New Haven, Conn.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 | JULY, 1933 | NO. 7

A NEW TYPE OF INSTALLATION FOR MEASURING SOIL AND WATER LOSSES FROM CONTROL PLATS[1]

H. V. GEIB[2]

The first installations to determine soil and runoff losses consisted of plats laid out on different slopes. At the foot of these plats large concrete or metal tanks were placed to catch all of the soil and water lost from the plats during rains. Even where the plats were as small as 1/100 acre, the catch tanks had to be so large that their construction was very expensive. In order to make possible the use of larger plats and at the same time cut down the cost of construction, it was highly desirable to devise some means whereby a definite and thoroughly representative aliquot of the runoff from the plats could be caught instead of the total amount. Consequently, work was carried on for more than a year, designing and testing different types of divisor boxes to obtain one which would satisfactorily separate out an aliquot which would give the same percentage at all stages of flow. There follows a detailed description of a type of divisor box which was found to work very satisfactorily, along with a description of the complete installation as it is now being used on the soil erosion and moisture conservation control plats at the Blackland Experiment Station at Temple, Texas.

DESCRIPTION OF INSTALLATION EMPLOYED

In the type of construction that has ordinarily been used for determining soil and water losses, one plat borders another so that it is essential to have some sort of dividing wall between the plats, extending into the ground to a depth of 3 feet or more. This wall is necessary in order that the roots of plants in one plat will not draw moisture and plant food from the one adjoining. Where only a shallow divider has

[1]Contribution from Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, cooperating with Texas Agricultural Experiment Station. Part of a thesis submitted in partial fulfillment of the requirements for the degree doctor of philosophy at Iowa State College. Published with the consent of the Chief of the Bureau of Chemistry and Soils. Received for publication October 27, 1932.

[2]Scientist in Soil Erosion, Bureau of Chemistry and Soils, In Charge, Blackland Erosion Station, Temple, Texas.

The author expresses appreciation to Dr. P. E. Brown for helpful suggestions in the preparation of this manuscript, and to Mr. O. R. Maxfield for his painstaking care in constructing the many types of divisor boxes tested.

been used there have been very noticeable border effects when the adjoining plat was planted to a different crop. When the width of plats was as small as 6 feet the border effects from both sides would affect practically the entire plat. Where plat walls extend to a depth of 3 feet or more border effects are seldom noticeable.

The disadvantages of deep plat dividing walls are their cost and the fact that a great deal of the soil has to be disturbed in order to make the installations. In some cases concrete walls have been used for plat dividers, but in most instances they have been made from heavy metal.

Fig. 1 shows a type of plat construction which does away with the necessity of having deep plat walls. These particular plats are 9 feet

FIG. 1.—Plan of erosion plats, with 6-foot alleyway (c) separating plats.

in width making room for three rows of cultivated crops, and all plats are separated from one another by 6-foot alleyways. Any size plat may be used, and the alleyways may be wider than 6 feet if desired. As shown in the illustration plat a is planted to corn and plat b to oats. The half of the alleyway c adjoining the corn plat is planted to corn and the half adjoining the oats plat to oats. Thus all of the border affects are confined to the plants that are in the alleyway. The plat walls in this type of illustration consist of 1 x 12 inch boards set 7 inches into the ground, so that 5 inches protrude above the surface. The boards are nailed to stakes which are driven into the ground at about 4-foot intervals. These stakes are set in the alleyways and thus do not interfere in any way with the plats. The function of this divider is mainly to confine to the plat and to the alleyways the rain water which falls on each of them. Having the same crop on each side of the plat wall makes deep dividers unnecessary.

The runoff from a plat passes into a concentration funnel at the foot of the plat, through a flume to a settling box which catches most of the soil washed from the plat, and from this through divisor boxes into a metal catch tank. (See Fig. 2.)

CONCENTRATION FUNNEL

The construction of the concentration funnel at the foot of the plat is shown in Fig. 3. The weir across the foot of the plat consists of a

2" x 6" by 9' timber set on edge in the ground, fastened to, and held in place by several 2 x 4's driven into the ground to a depth of 2 feet or more. The top of this weir must be kept level with the surface of the soil. For this reason it is desirable to have the top of the 2 x 6 several inches below the level of the plat and place a 2 x 2 or a 2 x 4 above it. This upper timber can be changed whenever necessary to keep it adapted to the level of the plat. This is very desirable when the rows are bedded. At the time of the year when the row centers are plowed out this upper timber can be removed, to be replaced later when subsequent cultivations have changed the level of the surface. The side walls of the concentration funnel consist of 2 x 12's. To the inside of these timbers 2 x 4's are spiked, and upon these rests the floor. This floor is constructed of a high grade tongue-and-groove flooring, or a cheaper grade of material may be used and covered with roofing tin. All joints which are likely to leak are covered with a coating of plastic roof cement over which a strip of tin is nailed. All wood which is to come in contact with the soil is double-dipped in creosote wood preservative.

FIG. 2.—Lower end of plats showing concentration funnel (a), flume (b), settling tank (c), and metal catch tank (d).

The settling tank is placed down the slope about 18 feet below the end of the plat. This makes it possible to cultivate the plats with a work animal, without having to turn around on the plats. Furthermore, when a deep box or tank is set directly at the foot of the plat it has been found to check seepage of underground water down the slope, causing a greater concentration of moisture in the subsoil. Installing tile drain at this point creates an unnatural condition, and brings about better drainage than exists under the remainder of the plat. Setting the box a distance down the slope overcomes this difficulty entirely. If a shallow settling tank is used, it may be set directly across the foot of the plat, thus making unnecessary the use of a concentration funnel and flume.

FIG. 3.—Weir timber (a) across foot of plat and concentration funnel with side walls (b).

FLUME

The flume which leads from the concentration funnel to the "settling" or "mud" tank is constructed by using 2 x 12's for the top and bottom of the flume and 2 x 6's for the side walls. The edges of the timber are covered with plastic cement before they are placed together to make them water-tight.

SETTLING BOX

Fig. 4 shows the settling box. When the tank is to be cleaned, the drain pipe can be swung down so that the outlet will be at any desired height, allowing water to be drained off slowly so as not to disturb the sediment in the box. A pipe set flush with the bottom of the tank may be opened to clean the box after the mud has been removed. The box is constructed of high-grade, tongue-and-groove flooring on a framework of 2 x 4 timbers. The upper rim is of 2 x 6's. Corners are water-proofed, when necessary, by tacking on a piece of angle tin over a coating of plastic roof cement.

FIG. 4.—Settling box, showing entrance of flume (a), attachment of divisor box (b), turn-down drain pipe (c), and location of floor drain (d).

SCREENING SYSTEM

Fig. 5 shows the location of a quarter mesh hardware cloth which screens back the trash, preventing it from entering the divisor box. Back of this screen, attached to the tank wall and completely shielding the outlet, is a double layer of fine-mesh window screening which is supported by heavy wires fastened at either side of the outlet. These screens effectively exclude from the divisor boxes all trash which otherwise might interfere with the proper functioning of the weir slots.

DIVIDING ARRANGEMENT

Fig. 6 shows settling tank, divisor boxes, and the metal catch tank. As the water passes through the settling tank all trash is caught and most of the soil washed from the plats settles to the bottom of the box. Only very fine soil remains in suspension and this passes with the water through the first divisor box where it is divided in such a way that only a small aliquot (in this case 1/11) passes into the second divisor box. This second box further divides the flow so that 1/5 of the water entering the box passes out into the catch tank. Thus, only 1/5 of 1/11, or 1/55, of the runoff material which leaves the mud box is caught in the catch tank. In case it is desired to save a still smaller aliquot, more and different sized divisor boxes may be installed in the series so that any desired aliquot may be obtained.

FIG. 5.—Framework covered with quarter inch mesh screening (a) and secondary screen (b) of fine window screening, to prevent trash from entering divisor box.

THE DIVISOR BOX

A great amount of experimental work was done in devising a type of weir that would separate out a definite aliquot which would be the same percentage at any stage of flow. Fig. 7 shows several types of divisor boxes which were tested out. Box a has one 3-inch and one ½-inch slot. Box b is similar, except that the larger slot is 6 inches wide. Box c has a ½-inch slot in the center with a 3-inch slot on each side. In boxes a, b, and c all slots are spaced 2 inches apart and have a 2-inch spacer next to the side walls. In box d there are no spacers, the aliquot being taken out by a ½-inch slot formed by two vertical fins set lengthwise in the center of the outlet. Box e, the latest designed, has nine identical ½-inch slots, equally spaced.

FIG. 6.—Settling box (a), divisor boxes (b and c), and metal catch tank (d).

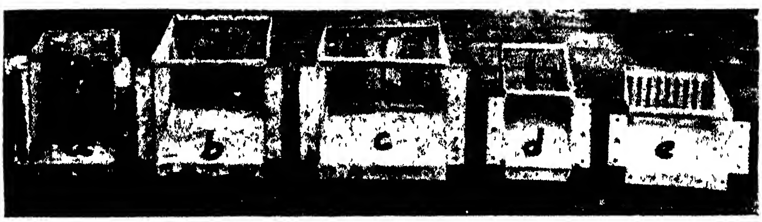

FIG. 7.—Divisor boxes showing several of the types of weirs that were tested.

In boxes a, b, c, and d the aliquot obtained through the narrow slot was a different percentage when the flow was low than when it was high. Box e, having all openings identical, was the only type that gave satisfactory results. Fig. 8 shows this divisor box with the flanges for attachment to mud box and the weir plate which carries nine slots in this case, the center one of which is attached to a separate drain spout so that the water from this slot can be carried either to another divisor box or to the catch tank, as desired. At the side of the divisor box shown in Fig. 8 is a baffle which is inserted in the divisor box as shown in the illustration. This baffle prevents eddying and cross currents in the water flowing through the divisor box and causes the water to move smoothly and in a straight line to the weir slots at the far end of the box.

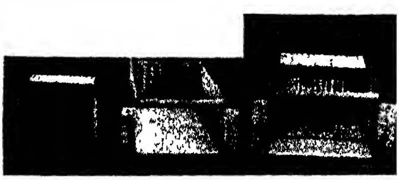

FIG. 8.—Type of divisor box found to work most satisfactorily, showing flange (a) for attaching to support; weir plate (b) having nine slots, the center one taking out the aliquot to be saved; the baffle (c) which is placed in the divisor box as in (d) to prevent water from eddying; baffle fins (e); and side wings (f) which hold baffle in place.

DETAILS OF DIVISOR BOX CONSTRUCTION

The weir plate containing the slots is made from rustproof 16 gauge Allegheny metal. The strip of metal from which this weir is made is 9 inches wide. The length depends upon the number of slots to be cut in the weir. The slots are stamped out with a die which cuts one slot at a time. Thus all slots are identical in every respect. A spacing device on the die insures that the space between all slots will always be the same. When the weir plates are handmade, it is difficult to get all the slots identical. The slot openings are 4 inches in height by ½ inch wide. The spaces between slots are ¾ of an inch. A ½-inch space is allowed at each end of the plate between the last slot and the side of the box.

FIG. 9.—Eleven-slot and nine-slot weir plates, showing angle (a) formed at top of plate, angle (b) at bottom of plate, end wings (c) for attachment of sides of divisor box, and strip (d) which is held in place by solder applied at hole (e).

After the slots have been stamped out, the top ½ inch of the plate is bent over to form a right angle (Fig. 9a) and the bottom inch is shaped in a similar manner (Fig. 9b), thus giving great rigidity to the weir plate. A 2-inch wing (Fig. 9c) is soldered on each end of the plate which provides attachment for the sides of the divisor box. These wings are set at right angles to the weir plate, and form a square corner at this point.

The operation of any divisor box requires that the bottom line of all outlet openings must be an absolutely straight line so that when water starts to flow through the weir plate it will start at the same moment through all slots. The accuracy of the die is not sufficient at this point, although the bottoms of the slots are apparently in line. To overcome this difficulty a strip of the Allegheny metal about 1 inch in width is placed on a planing lathe and worked down until the top line is perfectly straight. The roughness of the edges is smoothed off by passing lightly over fine sandpaper or emery cloth which is resting on a smooth surface. This planed strip (Fig. 9d) is then attached to the inner side of the wier plate so that the straight upper surface is about ¼ inch above the bottom of the slots. Holes are drilled through the strip (Fig. 9e), and through these holes solder is applied which holds the strip to the weir plate. Care must be taken that the top of the strip has close contact the full length of the weir plate and that there is no solder in the weir openings or on the top edge of the strip between openings.

The remainder of the divisor box is constructed from 24-gauge galvanized iron. The box is 24 inches long and 7½ inches high. The width depends upon the number of slots in the weir plate. As seen in Figs. 4 and 5, the front end of the divisor box which is attached to the settling tank is entirely open. All ubsequent boxes in the series have the front ends closed, except for an opening to allow entrance of the spout which brings the aliquot from the preceding box. These secondary boxes should have a piece of sheet iron about

2 inches wide and 6 inches high placed in a vertical position about 3 inches directly in front of the spout opening that brings the aliquot from the preceding box. This arrangement is to spread the water so that it will not be concentrated in the center of the box. All divisor boxes have tight-fitting lids to prevent trash from being blown into them.

CONSTRUCTION OF BAFFLE

The baffle (Fig. 8c) is made of 20-gauge galvanized iron. It is the same height as the divisor box. The baffle plates or fins (Fig. 8e) are about 7 inches high, 5 inches long, and are spaced about 2/3 inch apart. They are held in place by 4 quarter-inch stove bolts and are held apart by galvanized iron separators. The stove bolts pass through the fins and the separators so that a very rigid construction is obtained. These fins are placed approximately in the center of the baffle. The width of the baffle, in the center, is about 1 inch less than the width of the box. The length of the complete baffle is about 2 inches less than the length of the box. The baffle is set into the divisor box with the wings against the front end of the box so that the rear wings of the baffle lack about 2 inches of touching the weir plate of the divisor box. This will place the rear end of the fins about 10½ inches from the weir plate. When a narrower baffle was used, the water at high flow would be thrown too much to the center, causing the slots to deliver unequal aliquots. The length of the baffle fins, the space between fins, and the distance from the fins to the weir plate may vary as much as 10% without appreciably affecting the accuracy of the box.

Extreme care is necessary in the construction of the weir plates, yet the cost of construction is not high. The weir plates, complete with planed strip and side wings attached, can be made for from $4 to $6 each and the whole divisor box completely assembled, including weir plate, baffle, and lid, can be made for from $10 to $16, depending upon the number of slots in the weir plate.[3]

DETERMINING NUMBER OF WEIR SLOTS NECESSARY

The number of slots in the weir plate will depend upon the amount of water which must pass through the weir in a given time. It is recommended, however, that for small plats no plates be made with more than 11 slots, since at very low flows when only a mere trickle of water is passing through the weir, it is difficult to get all slots to start flowing at the same moment if they are too numerous. Each slot flowing at full capacity can be counted on to deliver somewhat more than 13 gallons of water per minute. In case 11 slots will not accomodate the anticipated runoff, it is recommended that two or more divisor boxes be installed side by side. The single slot aliquot from each of these divisor boxes may then be combined to pass through a smaller box, second in the series. It is recommended that this second box contain not over five weir slots, since with this number

[3]These boxes can be purchased from O. R Maxfield, Temple, Texas.

the flow is uniform even at the lowest flow rates, and the flow through this box will never be great. If a smaller aliquot than 1/55 is desired, a third or fourth box may be placed in the series.

ATTACHMENT OF DIVISOR BOXES

The attachment of the divisor boxes in series is shown in Fig. 10. An angle iron is attached to the bottom of the divisor box at the out-

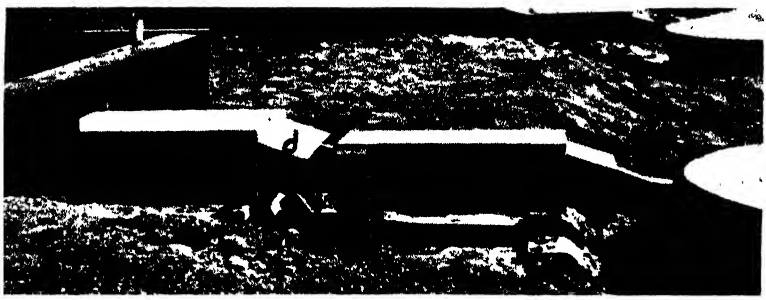

FIG. 10.—Two divisor boxes in series, showing angle iron (a) and leveling bolt (b) set in concrete block. The post (c) is for attachment of second box, and the sleeves (d) shield the weir plates from wind and rain

let end. Bolts set in concrete pass through this angle iron, and nuts above and below make it possible to keep the weir end of the divisor box absolutely level. The first adjustment is made by the use of a short hand level which is set on the strip which forms the bottom line of the weir slots. The final leveling is made by passing water through the box and adjusting the leveling screws so that water breaks through all the slots at the same moment. The posts which support the front end of the second divisor box in the series are also set in concrete This first box should be set at such a height that the bottom of the box is at least 7 inches below the bottom of the flume which brings the water into the settling tank. Each succeeding divisor box in the series should be set at least 4 inches below the preceding box so that the water will have free fall from one box to another. Fig. 10 also shows the shields attached to the weir end of the box, so that wind will not interfere with the operation of the weir and rain will not enter the box.

CATCH TANK

The tank which catches the aliquot from the runoff is constructed of 20-gauge galvanized iron and is made sufficiently large to hold the aliquot from the largest runoff anticipated. These tanks are reinforced on the outside by three vertical angle irons which are riveted to the sides of the tank. These angle irons are bent over the top of the tank, and they extend below the bottom a distance of 6 to 8 inches. This extension is set into concrete blocks which extend outward under the firm soil, thus giving anchorage so that the tanks will not be heaved out of the ground when it becomes saturated with rain water. The bottom inch of the angle iron may be bent to form a

right angle, or a bolt may be passed through it to give a better binding effect with the concrete. If the soil has a tendency to become water-logged, it is well to place 3 or 4 inches of reinforced concrete in the bottom of the tank to prevent buckling. A tub or garbage can may be set inside the catch tank. This will be sufficiently large to catch the usual runoff and is much handier to empty than is the catch tank.

DETERMINING THE AMOUNT OF RUNOFF AND EROSION

The settling tank is calibrated by pouring water into it in 5-gallon additions. At each addition the depth of water is marked with a punch on a metal strip which is attached to the side wall of the tank. After each rain the amount of water in the tank is recorded. After the water has been allowed to settle for about 24 hours, samples are taken to determine the amount of soil in the water. The adjustable drain pipe is then lowered and the water allowed to drain out slowly. Samples of the material remaining in the tank are then taken for moisture determination. The amount of water displaced by the total soil found to be in the tank is subtracted from the number of gallons of water and soil combined, thus giving the amount of water.

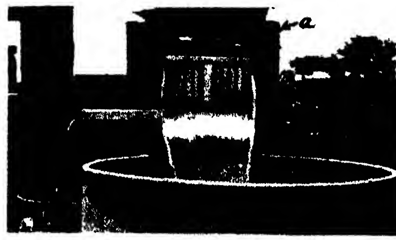

FIG. 11.—Testing a divisor box. The wooden box (a) receives water from a fire hydrant. Tank (b) catches the 1/11 aliquot from the center slot, while the water from the remaining 10 slots passes into the tank (c). These tanks are weighed to determine the amount of the aliquot. The accuracy of these divisors ranges from 98 to 100%, and the error is seldom greater than 1%.

The metal catch tank is calibrated in the same way as the settling tank, except that calibrations are made for each gallon of water added. After each rain the number of gallons in the tank is recorded. The material in the tank is stirred thoroughly and samples taken to determine the amount of soil in the water.

To determine the total soil washed from the plat, multiply the soil in catch tank by the number of weir slots in the series and add the soil in settling tank.

The total amount of water is determined similarly. If a small tub is placed in the catch tank, its contents may be determined by weighing or measuring and sampling for amount of soil. Samples are dried at approximately 105° C, and all computations are made on the basis of oven-dry weights. The areas of the concentration funnel and the mud tank are determined so that the amount of rain water which falls directly into these may be subtracted from the total amount caught.

If there is sufficient fall, it is desirable to set the first divisor box flush with the bottom of the settling tank. When this is done, a low dam must be built around the entrance of the divisor box to hold back the mud. Openings, fitted with stoppers, should be made near the bottom of the dam so that most of the water in the tank can be

TABLE 1.—*Aliquots obtained at different flow depths with various types of divisor boxes.*

Type of divisor box*	Depth of water flowing over outlets, in.	Aliquot through small slot		Error %
		Theoretical	By actual test	
One 3 in. slot; one ½ in. slot* ... (Fig. 9a)	¼	1/7	1/ 7.53	7.6
	½	1/7	1/ 6.98	0.3
	1½	1/7	1/ 6.70	4.3
	3	1/7	1/ 6.54	6.6
	3½	1/7	1/ 6.42	8.3
	4	1/7	1/ 6.63	5.3
	5	1/7	1/ 6.50	7.1
One 6 in. slot; one ½ in slot...... (Fig. 9b)	¼	1/13	1/16.3	25.4
	½	1/13	1/13.6	4.6
	1	1/13	1/12.4	4.6
	1½	1/13	1/12.54	3.5
	2	1/13	1/12.31	5.3
	2½	1/13	1/12.36	4.9
	3	1/13	1/12.50	3.8
	4	1/13	1/12.55	3.5
	5	1/13	1/13.01	0.1
	5½	1/13	1/13.00	0.0
One 6 in. slot; one ½ in slot; same as above but constructed by more accurate methods ... ... (Fig. 9b)	¼	1/13	1/13.79	6.1
	1½	1/13	1/12.53	3.6
	3	1/13	1/12.21	6.1
	4½	1/13	1/12.59	3.2
	6	1/13	1/12.89	0.8
Two 3 in. slots; one ½ in. slot ... (Fig. 9c)	¼	1/13	1/14.40	10.8
	½	1/13	1/13.22	1.7
	1½	1/13	1/13.35	2.7
	3	1/13	1/13.045	0.3
One ½ in. slot; remainder of end open; 3½ in. opening on each side of center slot... .... (Fig. 9d)	⅛	1/15	1/13.17	12.2
	¼	1/15	1/12.58	16.1
	½	1/15	1/14.19	5.4
	1	1/15	1/14.33	4.5
	2	1/15	1/13.62	9.2

*A large number of tests were made on each type of box, using different spacings between slots, different types and locations of baffles, etc.

drained out through the divisor boxes, thus making it unnecessary to calibrate the settling tank or to determine the amount of water held back in it. The quarter-mesh removable screen should be placed outside this dam.

TESTING DIVISOR BOXES

The accuracy of the divisor boxes described above was determined by testing them at all stages of flow, as shown in Fig. 11. The divisor box was attached to a wooden tank into which water was run from a fire hydrant. The aliquot from the center slot was caught in tank b and the remainder of the water in tank. c. The amount of water in each tank, and the size of the aliquot, was determined by weighing.

TABLE 1.—*Concluded.*

Type of divisor box*	Depth of water flowing over outlets, in.	Aliquot through small slot		Error %
		Theoretical	By actual test	
New type multi-slot box; five slots, each ½ in wide, spaced ¼ in. apart... (Fig. 9c)	¼	1/5	1/ 5.032	0.6
	½	1/5	1/ 5.038	0.8
	¾	1/5	1/ 5.004	0.1
	1½	1/5	1/ 5.038	0.8
	2	1/5	1/ 5.031	0.6
	3	1/5	1/ 4.992	0.2
Same type as above, but with nine slots. (Fig. 9e)	3/16	1/9	1/ 9.15	1.7
	¼	1/9	1/ 9.10	1.1
	½	1/9	1/ 9.085	0.9
	¾	1/9	1/ 9.08	0.9
	1¼	1/9	1/ 9.04	0.4
	2	1/9	1/ 9.07	0.8
	3	1/9	1/ 9.06	0.7
Same type as above, but with 11 slots. (Fig. 9e)	⅛	1/11	1/11.145	1.3
	¼	1/11	1/10.80	1.8
	½	1/11	1/10.95	0.5
	¾	1/11	1/11.00	0.0
	1	1/11	1/10.91	0.8
	2¼	1/11	1/11.00	0.0
	3½	1/11	1/10.90	0.9
Same type as above ... (Fig. 9e)	⅛	1/11	1/11.18	1.6
	¼	1/11	1/11.025	0.2
	⅓	1/11	1/11.20	1.8
	½	1/11	1/10.98	0.2
	1	1/11	1/10.93	0.6
	1¼	1/11	1/11.02	0.2
	2	1/11	1/10.8	1.8
	2½	1/11	1/10.9	0.9
	3	1/11	1/10.96	0.4
	3½	1/11	1/10.95	0.5
Same type as above.... (Fig. 9e)	⅛	1/11	1/10.90	0.9
	¼	1/11	1/11.043	0.4
	⅓	1/11	1/10.82	1.6
	½	1/11	1/10.96	0.4
	1	1/11	1/10.973	0.2
	2	1/11	1/10.865	1.2
	3	1/11	1/11.00	0.0
	3½	1/11	1/10.96	0.4

*A large number of tests were made on each type of box, using different spacings between slots, different types and locations of baffles, etc.

ACCURACY OF DIVISOR BOXES

The accuracy of the new type divisor box,[4] and of several of the

[4]Since this article was submitted for publication a larger divisor box has been developed. This has slots 1 inch wide, spaced 1 inch apart. The largest box that has been made to date has 15 slots, each 15 inches high. Such a box will deliver in excess of 6,000 gallons of water per hour. When this box is used, it is recommended that the second divisor in the series be of the small type with nine ½-inch slots. A third box having five ½-inch slots may be last in the series. This combination will take out an aliquot of 1/675 of the total runoff.

other types that were tested, is shown in Table 1. The data are representative of the many tests that were made.

It will be noted from Table 1 that with all divisor boxes having weir slots of different dimensions, the aliquot obtained from the small slot was a different proportion at different flow depths. The tests showed that the error ranged from less than 1% to more than 25%. The greatest error was at very low flow rates. The water tended to bank up behind the weir plates to a depth of about 3/16 to 1/4 inch before breaking over. The depth depended somewhat on the width of the slot. Therefore if one slot was wider than another, it was difficult to get them to start to flow at the same moment when the flow rate was at a minimum. Once the flow had started, the head could be reduced considerably and water would continue to run through the slots at a less depth than was required to start the flow. Only when all slots were made identically the same and spaced equal distances apart was any great degree of accuracy consistently obtained.

The new multi-slot divisor box, tested with 5, 9, and 11 equal slots, gave by far the most satisfactory results of all boxes tested. In none of the trials did the error run greater than 2%. This is considered sufficiently accurate for the type of work this box was designed to perform.

SUMMARY AND CONCLUSIONS

After testing a large number of different kinds of divisor boxes, a type was finally evolved which gave practically the same aliquot at all stages of flow. The outlet or weir end of this box consisted of a number of identical rectangular slots, stamped out with a die to insure greater accuracy and uniformity. This multi-slot divisor box was found to be very accurate and entirely suitable for use alone or in series to obtain a definite aliquot of the runoff from erosion control plats. Its construction is described in detail and a description is given of a complete installation as it is now in operation at the Blackland Erosion Experiment Station at Temple, Texas.

THREE YEARS RESULTS WITH AN INTENSIVELY MANAGED PASTURE[1]

D. S. FINK, G. B. MORTIMER, and E. TRUOG[2]

It is becoming well recognized that permanent pastures in this country are no longer producing profitably, nor as they should. In many cases the fertility of the soils has become depleted. Until recent years, systematic rotational grazing has been practically unknown, and the restitution of grazed away fertility, likewise, has rarely been practiced. Although bad grazing practices undoubtedly have been an influence in reducing the productivity of these pastures, unpublished data from the Wisconsin Agricultural Experiment Station show that this is inconsequential compared to the major ill of depleted fertility. For the most part, because of improper management, these pastures have been allowed to drift into a deplorable condition. For the past several years the Wisconsin Station has carried on extensive investigations relative to grazing management and fertilization, and this paper is a progress report on one phase of the work, having to do with systematic rotational grazing and heavy fertilization, especially with nitrogen.

ORIGIN OF THE INTENSIVE SYSTEM OF PASTURE MANAGEMENT

Rotational grazing has been practiced to a certain extent in England and other European countries for many years. In Germany, during the early part of the nineteenth century, Falke[3] carried on extensive pasture investigations involving not only systematic rotational grazing, but also the use of artificial fertilizers. It was, however, not until near the close of the war and thereafter that commercial nitrogen fertilizers became cheap and plentiful enough to make heavy nitrogen fertilization practical in conjunction with systematic rotational grazing. The urgent need of vast quantities of nitrogen compounds for the manufacture of explosives for war purposes brought about the perfection of the methods of manufacturing these compounds synthetically so that the free nitrogen of the air could be utilized on a grand scale.

In Germany, as a result of the war, there thus existed on the one hand an abundance of nitrogen compounds that might be used either for explosives or fertilizers, and on the other, a deficiency of concentrates for the feeding of dairy cows and other livestock. Impelled by this situation, Professor Warmbold at the Hohenheim Station, in 1916, inaugurated the most thorough and searching experiment of the time to test a system of pasture management involving not only

[1]Joint contribution from the Departments of Agronomy and Soils, University of Wisconsin, Madison, Wis. This work was supported in part by a fellowship grant from the American Cyanamid Company, New York City. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication November 14, 1932.

[2]Fellow, Professor of Agronomy, and Professor of Soils, respectively.

[3]FALKE, F. Die Dauerweiden, Bedeutung, Anlage, und Betrieb derselben unter besonderer Berücksichtigung intensive Wirtschafts Verhältnisse. Hanover, Germany. 1907.

systematic rotational grazing, but particularly, heavy annual dressings of commercial nitrogen fertilizers as well as potash and phosphate fertilizers when needed. One point he wished to determine definitely was the extent to which the protein concentrates in a dairy ration might be eliminated if the pasture is heavily fertilized and properly grazed. The results of this experiment were so definite, so far reaching, and soon became so widely known that a system of pasture management involving both systematic rotational grazing and fertilization of the kind described is sometimes referred to as the Hohenheim system of pasture management.

MECHANICS OF THE SYSTEM

Briefly, the mechanics of the system when fully carried out are as follows. The pasture is divided into four or five paddocks, their size depending upon the size of the herd. Usually about 1 to 2 acres are allowed per 10 cows, so that, with a herd of 30 cows, each of the four or five paddocks would have an area of about 3 to 5 acres, depending upon the productivity of the pasture. Each paddock is fertilized with phosphate and potash when needed, and particularly with liberal amounts of nitrogen every year in one or more applications. During the grazing season, the cattle are rotated progressively from paddock to paddock at intervals of about a week. Each paddock is thus rapidly grazed in turn, or in a sense mowed, whenever the grass reaches a height of 4 to 5 inches. The young stock and dry cows are kept separate from the milk cows and follow on each paddock as the milkers are advanced. They graze on the remnants and less palatable grass. After they have finished and moved on, it is often desirable to harrow the paddock so as to scatter the droppings, and if additional nitrogen is to be added, it is applied at this stage. If the cattle are unable to keep the grass down due to very favorable growing conditions, mowing when the grass reaches a height of 5 to 6 inches should be resorted to so that it will remain in a highly vegetative condition, keeping it palatable and preventing it from going into a semi-dormant condition.

ADVANTAGES OF THE SYSTEM

This system makes possible the attainment of the following desirable results. Heavy fertilization, especially with nitrogen, makes grazing possible at least 2 weeks earlier in the spring, lengthens the grazing season in midsummer and fall, and usually doubles or trebles the production of grass, which, if grazed when young, is so rich in minerals and protein as to approximate protein concentrates in feeding value.

Grazing of a limited area at one time forces the cattle to remove completely and uniformly all of the pasturage on one area in a relatively short period. In effect, it simulates machine mowing. This prevents the development of patches of mature grass that are no longer palatable, and thus usually run to waste. The rest period prevents undue over-grazing, and permanent injury of the more palatable areas of grass. It gives the grass a full opportunity to

produce new leaf surface, making possible rapid photosynthesis and quick new growth. During this period, the pasture is washed and cleansed by rain and becomes platable again with a new growth. That this is true is shown by the fact that after the cattle have been on a paddock for several days, even though there is still sufficient feed, they become restless and discontented, whereas, when they are turned into a fresh paddock they begin to graze with relish as soon as they enter. Continuous open grazing, on the other hand, always produces areas of neglected grass, and the whole pasture becomes more or less unpalatable and unproductive too early in the season.

The ideal system of mowing or removing the grass so as to make possible the production of the greatest amount of highly nutritious feed is, undoubtedly, one in which the grass is uniformly mowed to a height of about 1.5 inches whenever it reaches a height of 4 or 5 inches, and is allowed, without disturbance, to reproduce this growth between mowings. The aim of rotational grazing is to approach this ideal system as nearly as possible. Under this management, the turf becomes thicker and better each year, weeds gradually disappear, and the productivity of the pasture is rapidly brought to a high level.

PLAN OF THE EXPERIMENT

The object of the experiment reported here was to determine the adaptability to Wisconsin dairy farms of an intensive system of pasture management involving systematic rotational grazing and annual applications of nitrogen in the form of cyanamid, as well as potash and phosphate fertilizers when needed.

In searching for a dairy farm on which to conduct this experiment, the writers were fortunate in securing the cooperation of W. D. Hoard, Jr., making it possible to conduct it on the famous Hoard's Dairyman Farm at Fort Atkinson, Wisconsin. On this farm of 250 acres, a large herd of pure bred Guernsey cattle has been maintained for many years. The permanent pasture comprised an area of about 35 acres of river bottom land, the soil being a Clyde sandy loam for the most part. Certain portions of the pasture tend to be mucky and are poorly drained.

At the start of the experiment in the spring of 1929, the pasture was divided into five paddocks of 5.5 acres each, leaving an extra paddock of about 8 acres which was later plowed and sowed to sudan grass annually to serve as supplementary pasture during the drier part of the season. The arrangement and notation of the paddocks are shown in Fig. 1. Water is piped to each paddock.

This pasture had been in permanent grass for over 20 years. The turf, consisting largely of bluegrass with scattered timothy, red top, and a little white clover, was thin and weedy. No manurial treatment had ever been given the field, and the soil was in a low state of fertility.

The fertilizer treatments for the individual paddocks are given in detail in Table 1. Paddocks A, B, C, and D were given a complete fertilizer treatment of nitrogen, phosphate, and potash. Thereafter, nitrogen alone was added annually to paddocks A, C, and D, while paddock B received no further fertilizer treatment, and, after the

first year, is referred to as the mineral fertilized paddock, since the phosphate and potash originally added were ample for 5 years, while the effects of the nitrogen disappeared largely after the first year. Paddock E was left unfertilized to serve as a check on the effects of

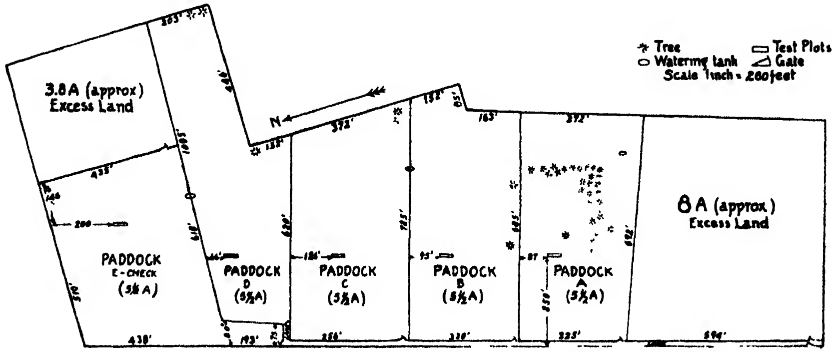

FIG. 1.—Arrangement of pasture for management experiment, Hoard's Dairy Farm, Ft. Atkinson, Wis.

fertilization. It produced so poorly, and was so badly damaged by white grubs in 1930 that it was abandoned after the first year.

The herd, consisting usually of 50 to 60 head, was divided into milk cows and young stock. They were turned onto the pasture in the spring as soon as the grass reached a good grazing height. The young stock followed the milk cows in regular rotation as the different paddocks were successively grazed.

TABLE 1.—*Fertilizer treatments of paddocks.**

Season	Treatment giving pounds per acre of fertilizer constituents applied
	Paddock A, Complete Fertilizer
1929	N, 100; P_2O_5, 100; K_2O, 100; applied in spring
1930	N, 100; applied in spring
1931	N, 100; applied in spring
	Paddock B, Minerals only After 1929
1929	N, 100; P_2O_5, 100; K_2O, 100; applied in spring
1930	No additional fertilizer
1931	No additional fertilizer
	Paddock C, Complete Fertilizer
1929	N, 100; P_2O_5, 100; K_2O, 100; applied in spring
1930	N, 100; applied in spring
1931	N, 100; applied in fall of 1930
	Paddock D, Complete Fertilizer
1929	N, 100; P_2O_5, 100; K_2O, 100; applied in spring
1930	N, 100; applied in spring
1931	N, 100; applied in spring

*Nitrogen applied as cyanamid, 22% N; phosphate as 45% superphosphate; potash as 50% muriate of potash.

SEASONAL DISTRIBUTION OF RAINFALL, 1929–31

The three pasture seasons of 1929–31 were drier than normal, as noted in Table 2, which gives a comparison of the total rainfall together with its distribution for the three seasons and also the average for a 19-year period.

TABLE 2.—*Precipitation in inches during pasture season at Fort Atkinson.*

Year	May	June	July	Aug.	Sept.	Total for 5 months
1929	2.60	4.66	4.06	0.58	2.62	14.52
1930	3.90	5.84	2.13	0.29	2.05	14.30
1931	2.04	3.17	1.84	2.33	4.93	14.33
19-year average	4.15	4.14	4.09	3.54	3.19	18.52

The productivity of the pasture in 1929 was greater than in 1930 and 1931 because of the greater precipitation in July, and also in early spring, during March and April, for which data are not given. The winters and springs previous to the 1930 and 1931 pasture seasons were also much drier than normal.

CARRYING CAPACITY OF THE PASTURE

The carrying capacity of the pasture for the three seasons is given in detail in Table 3. It will be noted that under complete fertilization, the pasture season was lengthened because of earlier grazing in the spring and more pasture in midsummer and late fall, so that in all from 4 to 8 weeks more grazing was secured with complete fertilization than with no fertilization or mineral fertilization only. During the periods of July 20 to August 3, 1930, and July 15 to September 7, 1931, the herd was grazed on supplementary pasture because of severe drouth cutting off the growth of bluegrass

Of the data shown in Table 3, those expressing the cow pasture days per acre give an accurate measure of the amount of grass produced under the different treatments, and it will be noted that in 1929 a completely fertilized acre produced about three times as much pasturage as an unfertilized acre. In this discussion a cow pasture day refers to a full grazing day, from 7:00 a.m. to 5:00 p.m., during which time ample feed was present to satisfy quickly the appetite of every cow in the herd. Likewise, a heifer pasture day (2-year-old heifers), on the pasture 24 hours per day, is calculated as being equivalent to three-fourths of a cow pasture day.

It will be noted that in 1931 the calculated area required per cow is slightly less for mineral fertilization only than for complete fertilization, although the latter treatment gave more than twice the number of cow pasture days per acre than the former. In explanation of this, it should be recognized that the calculated area required per cow is not a measure of the total seasonal production, but simply a measure of the intensity of grazing during the period that the area was grazed. Accumulation of more grass before grazing started on the mineral fertilized paddock accounts for this, as does also the restriction of

grazing to the period that is most favorable for the growth of the pasture grass.

TABLE 3.—*Length of pasture season, cow pasture days, and acres of pasture required per cow under various fertilizer treatments.*

	1929		1930		1931	
	Complete fertilization, paddocks A, B, C, D	No-fertilizer, paddock E	Complete fertilization, paddocks A, C, D	Mineral fertilization only (N in 1929), paddock B	Complete fertilization, paddocks A, C, D	Mineral fertilization only (N in 1929), paddock B
Beginning and end of grazing periods	May 22–Oct. 9	June 1–July 31; Stcp. 21–Oct. 9	May 4–July 19; Aug. 4–Sept. 22	May 21–July 19; Aug. 4–Sept. 5	May 12–July 14; Sept. 8–Oct. 21	June 9–July 14; Sept. 8–Sept. 15
Length of pasture season in grazing days	140	80	125	93	103	42
Acreage allowed per cow during grazing season..........	0.54	1.00	0.48	0.55	0.48	0.41
Yield in cow pasture days per acre.....	257	81	257	167	212	102

The Massachusetts[4] and Ohio[5] Stations have reported on similar pasture experiments, and in Table 4 their data and ours for cow

TABLE 4.—*A comparison of cow pasture days obtained with different fertilizer treatments of permanent pasture at three experiment stations.*

Year	Cow pasture days an acre with treatments indicated		
	Unfertilized	Minerals only with nitrogen in 1928 at Mass. and in 1929 at Ohio and Wis.	Complete fertilization
		Massachusetts	
1928	88	—	197
1929	97	139	227
		Ohio	
1929	—	—	315
1930	—	159	166
		Wisconsin	
1929	81	—	257
1930	—	167	257
1931	—	102	212

[4]FOLEY, R. C., Montague, E. J., and Parsons, C. H. Intensive grassland management. Mass. Agr. Exp. Sta. Bul. 262. 1930.

[5]SALTER, R. M., and Yoder, R. E. The intensive management of permanent pasture in dairy farming. Ohio Agr. Exp. Sta. Bimonthly Bul. 152:155–163. 1931.

pasture days under various fertilizer treatments are given for comparative purposes. The data of the three stations show the same general trend and emphasize the importance of nitrogen fertilization in addition to minerals in increasing the number of cow pasture days per acre.

COMPARATIVE COSTS OF PRODUCING MILK WITH NO FERTILIZATION, WITH MINERAL FERTILIZATION, AND WITH COMPLETE FERTILIZATION

Table 5 is a credit and expense account for the differently fertilized paddocks calculated on a basis of one cow for a period equivalent to the length of the grazing season each year under complete fertilization.

The milk produced by one cow on pasture was determined by multiplying the length of the pasture season in days by the average daily milk production per cow. The differences between the milk produced by one cow on the completely fertilized paddocks and on the untreated paddock in 1929 and on the mineral treated paddock in 1930 and 1931 represent the amounts of milk which would have to be produced through manger feeding in the case of the untreated or mineral treated paddocks to equal the milk produced through pasturage on the completely fertilized paddock.

The feed costs are actual for the period reported. When the cows were on pasture, oil meal was not included in the ration, and they were fed 1 pound of concentrates to every 4 pounds of milk produced. When roughage was supplied in the barn, the cows were fed 1 pound of concentrates to 3 pounds of milk, and the oil meal was included in the grain ration. An itemized list of feed costs for the various comparisons made is given in Tables 6 and 7.

The fertilizer costs each year include the cost of the nitrogen for that year plus one-fifth of the cost of the original mineral treatment. Present indications are that the phosphate and potash applications made in 1929 were amply heavy to suffice for a period of at least 5 years. The extra labor required during the time roughage was fed in the manger is conservatively figured at 2 cents a cow per day. The cost to produce milk per cwt. is obtained by dividing the total expenditures per cow by the cwts. of milk she produced. The total milk credit per cow, minus the expenditures listed, gives the balance left for milking, overhead, and profit. The milking and overhead charges are the same per cwt. of milk, whether the milk is produced on pasture or by manger feeding.

On the basis of the data in Table 5, the cost to produce milk exclusively with manger feeding, not considering overhead and milking costs, was $1.34 per cwt. in 1929, $1.23 in 1930, and $1.04 in 1931. Reference to Table 5 shows that these costs are from 35 to 74% higher than when the cows obtained their feed from pasture. This shows clearly the desirability of lengthening the pasture season as much as is possible and practical in order to get the advantage of lowered production costs over a longer period.

It will be noted that the annual applications of nitrogen are at the rate of 100 pounds per acre. This, while not excessive, is probably

TABLE 5.—*Permanent pasture balance sheet calculated on basis of one cow, giving returns and costs under various fertilizer treatments with cost of producing 100 pounds of milk exclusive of milking and certain overhead charges.*

	1929		1930		1931	
	Complete fertilizer	No fertilizer	Complete fertilizer	Mineral fertilizer (N in 1929)	Complete fertilizer	Mineral fertilizer (N in 1929)
Pasture Season, Returns per Cow, etc.						
Length of pasture season in days exclusive of emergency pasture....	140	80	125	93	103	42
Additional days barn feeding, incomplete vs. complete fertilization..........		60		32		61
Milk production per cow per day, average of herd on permanent pasture	22.5	22.5	22	22	19.1	19.1
Pounds of milk produced per cow while on pasture. ...	3,150	1,804	2,750	2,046	1,967	802
Pounds of milk which must be produced by barn feeding		1,346		704		1,165
Total pounds of milk produced during period equal to pasture season with complete treatment	3,150	3,150	2,750	2,750	1,967	1,967
Selling price of milk per 100 pounds.	$2.50	$2.50	$2.35	$2.35	$2.00	$2.00
Milk credit per cow.......	$78.75	$78.75	$64.62	$64.62	$39.34	$39.34
Expenditures per Cow						
Land required per cow in acres, Table 3.	0.54	1.00	0.48	0.56	0.48	0.41
Feed, Tables 6 and 7........	$12.70	$23.30	$9.53	$14.86	$4.38	$12.45
Fertilizer..................	$7.60		$8.00	$1.40	$6.92	$1.04
Field costs, fencing, etc.	$0.97	$1.80	$0.86	$0.99	$0.86	$0.73
Land rental	$3.24	$6.00	$2.88	$3.36	$2.88	$2.46
Extra labor required for barn feeding.............		$1.20		$0.64		$1.22
Total expenditures listed....	$24.47	$32.30	$21.27	$21.19	$15.04	$17.90

TABLE 5.—*Concluded.*

	1929		1930		1931	
	Complete fertilizer	No fertilizer	Complete fertilizer	Mineral fertilizer (N in 1929)	Complete fertilizer	Mineral fertilizer (N in 1929)
Returns and Milk Production Costs						
Credit per cow less expenditures per cow, or balance left for milking costs, overhead, and profit	$54.28	$46.45	$43.35	$43.43	$24.30	$21.44
Cost of producing 100 pounds of milk, including feed, fertilizer, field and land costs, but not milking and overhead charges	$0.78	$1.02	$0.77	$0.77	$0.76	$0.91
Cost of producing 100 pounds of milk, all manger feeding, exclusive of milking and overhead charges		$1.34		$1.23		$1.04

more than should be recommended under the rainfall conditions which prevail in this section where the amount of feed which can be produced on permanent pastures after midsummer is always greatly limited by a lack of water. This matter needs further consideration since a material reduction in cost of fertilization is possible in this way.

Items of cost in milk production, such as depreciation of buildings and equipment, cost of labor for milking, and cost of light and heat used in the barn and milk house present difficulties when an attempt is made to evaluate them. Since they are fixed charges, it is not necessary to include them in a comparison of the cost of producing milk on pasture and manger feeding.

EFFECT OF AN INTENSIVE SYSTEM ON THE HERD

The milk cows have shown no distinct signs of gain or loss in weight while on the intensively managed pasture, as noted in Table 8, and they have always come off the pasture each fall in the best of physical condition.

In 1931, the young stock were fed 2.5 pounds of grain per head each day. The gain in weight that year, shown in Table 8, is more than double that of 1929 and 1930, during which time they did not receive concentrates while on pasture.

TABLE 6.—*Supplementary feeds and costs (actual) per cow during grazing period for the various fertilizer treatments.*

	Complete fertilizer, 1929	No fertilizer, 1929	Complete fertilizer, 1930	Mineral fertilizer, 1930	Complete fertilizer, 1931	Mineral fertilizer, 1931
Pasture season in days. . . .	140	80	125	93	103	42
Pounds of concentrates fed	787	451	687	311	492	200
Cost of concentrates fed . . .	$11.17	$6.40	$7.96	$5.92	$3.09	$1.25
Pounds of silage fed	510		523	313	430	80
Cost of silage fed	$1.53		$1.57	$0.94	$1.29	$0.25
Total feed cost while cow is on pasture.	$12.70	$6.40	$9.53	$6.86	$4.38	$1.50
Total calculated cost of feeds for time not on pasture, from Table 7.	——	$16.90	——	$8.00	——	$10.95
Grand total cost of manger feeding required for period equal to grazing period with complete fertilizer . .	$12.70	$23.30	$9.53	$14.86	$4.38	$12.45

TABLE 7.—*Additional feeds and costs calculated per cow for the period of manger feeding equal to the extra pasture days gained from complete fertilizer over other treatments.*

	No fertilizer, 1929	Mineral fertilizer, 1930	Mineral fertilizer, 1931
Manger feeding days equal to extra pasture days gained from complete treatment . .	60	32	61
Pounds of concentrates necessary.	446	234	388
Cost of concentrates.	$ 6.82	$3.01	$ 3.02
Pounds of silage necessary.	1,200	640	813
Cost of silage.	$3.60	$1.92	$2.44
Pounds of hay necessary.	720	383	732
Cost of hay	$6.48	$3.07	$5.49
Total calculated cost.	$16.90	$8.00	$10.95

TABLE 8.—*Weights in pounds of animals at beginning and end of grazing seasons.*

Year	Average weights in spring		Average weights in fall		Average gains or or losses	
	Milk cows	Young stock	Milk cows	Young stock	Milk cows	Young stock
1929	1,015	720	983	750	—32	+ 30
1930	984	697	990	752	+ 6	+ 55
1931	1,042	534	1,020	662	—22	+128

CONDITION OF PASTURE AFTER THREE YEARS

A turf, very thin and weedy at the start of the experiment, is now, after 3 years, quite thick, uniform, and comparatively free of weeds throughout the completely fertilized paddocks. These paddocks have been heavily grazed without apparent injury, and the thickening of the turf under these conditions shows that Kentucky bluegrass is an excellent permanent pasture grass. It is inherently persistent and makes a quick recovery between periods of grazing when moisture supplies are adequate and temperature and soil fertility are favorable, particularly with nitrogen at a high plane. Grazing down to a height of 1.5 to 2 inches is not harmful to the productivity of this grass. The disappearance of the weeds is due to the fact that in rotational grazing they are either consumed or mowed while young, together with the lack of ability to cope with a thick turf or rapidly growing grass.

The influence of cyanamid on the reaction of the soil is shown in Table 9.

TABLE 9.—*The reaction (pH) of the soil at various depths on the different paddocks after 3 years.**

Soil layer, inches	Paddock A, 1,500 lbs. cyanamid	Paddock B, 500 lbs. cyanamid	Paddock C, 1,500 lbs. cyanamid	Paddock D, 1,500 lbs. cyanamid	Paddock E, no fertilizer
0–1	5.7	5.8	6.3	6.7	5.3
1–2	5.1	5.8	5.5	6.5	5.6
2–3	5.1	5.8	5.5	6.3	5.6
3–4	5.1	5.8	5.5	6.3	5.6
4–5	5.1	5.8	5.5	6.3	5.6

*Paddocks A, B, C, and D had received phosphate and potash in the beginning.

It is to be noted that where cyanamid has been applied annually at the rate of 500 pounds an acre for the past 3 years, the acidity of the soil in the surface inch has been reduced quite markedly. The change in acidity is mentioned here in connection with weed control, as noted by field observations. At the start of the experiment, portions of paddocks A, B, and D were badly infested with sheep sorrel. By the end of the third pasture season this weed had entirely disappeared in paddocks A and C; however, it is still quite abundant in paddock B, which received only one application of cyanamid.

The turf on the fertilized paddocks is today in excellent condition for future production, while that on the two areas marked excess pasture (Fig. 1), including paddock E, was completely destroyed by the white grubs in 1930. It appears to be a significant fact that white grub injury of permanent grasslands is not nearly as pronounced when they are under a program of systematic management.

SUMMARY

This paper is a progress report of 3 years work on an experiment designed to determine the adaptability to Wisconsin dairy farms of an intensive system of pasture management involving systematic rotational grazing and annual applications of nitrogen in the form of calcium cyanamid, as well as potash and phosphate fertilizers when needed. The experiment is located on the Hoard's Dairyman Farm where a purebred herd of 50 to 60 head of Guernsey cattle is maintained. The permanent pasture on this farm consists of about 35 acres of river bottom land. The soil is a Clyde sandy loam for the most part, and it was in a rather low state of fertility, having been pastured for more than 20 years without fertilization.

For the purpose of the experiment, 27.5 acres of the pasture were divided into five equal-sized paddocks of 5.5 acres each, leaving an extra paddock of 8 acres which was later used to grow sudan grass to serve as supplementary pasture. At the start of the experiment, four paddocks were fertilized with phosphate, potash, and nitrogen, which provided for 100 lbs. per acre of P_2O_5, K_2O, and nitrogen, respectively. The fifth paddock was not fertilized. After the first year, three of the fertilized paddocks received 100 lbs. per acre of nitrogen each year, while the fourth fertilized paddock received no additional fertilizer and from then on is referred to as the mineral treated paddock. The herd was divided into milk cows and young stock, and the paddocks were grazed in a systematic rotational manner, the young stock following the milk cows to complete the grazing of each paddock.

The outstanding results of the experiment to date are as follows. During the 3-year period, the completely fertilized paddocks had an average carrying capacity of one cow per 0.5 acre for a pasture season of 128 days; the mineral fertilized paddock, during the last 2 years, had a carrying capacity of one cow per 0.48 acre for 67 days. The unfertilized paddock, during the first year, had a carrying capacity of one cow per acre for 80 days. This paddock produced so poorly and became so badly infested with white grubs that it was abandoned after the first year as far as being a part of the permanent pasture. Nitrogen in addition to minerals is essential for the production of an abundance of high protein grass and for the development and maintenance of a satisfactory turf.

Expressing the results in another way, it may be stated that during the first year the completely fertilized area produced about three times as much pasturage as an unfertilized area. Omission of nitrogen after the first year caused a decrease of pasturage of 35% the next year and about 50% the second year, and is rapidly causing the production of this paddock to revert to its original low level.

The average cost for the 3-year period of producing milk per cwt. on pasture receiving complete fertilization was 43 cents less than it was with manger feeding. This emphasizes the importance of lengthening the grazing season as much as possible, which may be done by proper fertilization and grazing management.

The beneficial effect of the fertilizer treatment on the turf is very marked. It has been greatly thickened and improved, and weeds have largely disappeared. The pasture is now at a much higher producing level than it was in the beginning. The use of cyanamid over a period of 3 years has reduced the acidity of the soil quite markedly in the surface inch. The injury of turf by the white grub, so common in permanent grass pastures in this section, has been practically eliminated to date under this system of management.

Under Wisconsin conditions, where midsummer droughts are common, it is essential that supplementary pasture, such as sudan grass and meadow aftermaths, be provided to fill in when the permanent pasture no longer supplies sufficient grass. This period usually sets in between middle July and August 1.

The results to date indicate that many Wisconsin dairy farmer could, with profit, adopt in whole or in part some form of pasture management involving systematic, rotational grazing and fertilization.

THE VALUE AND APPLICATION OF GROWTH CURVES TO FIELD PLAT EXPERIMENTS[1]

K. H. W. KLAGES[2]

In any experiment, field plat or otherwise, it is good practice to accumulate data on as many phenomena as may be measured or visualized by the experimenter. Not infrequently data on points of apparently little immediate significance are found to be of considerable value in the final analysis and interpretation of the results.

More or less standardized notes are taken by most workers in variety test and other type of field plat experiments. Such notes deal in most instances mainly with the characteristics of headed or mature plants. The yield per plat is without doubt the most significant and valuable criterion of field plat results. A complete set of notes is often of value, however, in arriving at some workable basis for explaining the superior or inferior performance, as the case may be, of a variety or strain or plat treated in any specified manner. Aside from the time interval required by plants to complete the period from emergence to heading, little attention is usually given to the exact course of development of plants grown on field plats during the true vegetation phase. Yet, the final performance of crops is to a large degree determined by their reaction to prevailing climatic conditions throughout that stage.

[1]Contribution from the Department of Agronomy, South Dakota Agricultural Experiment Station, Brookings, S. Dak. Received for publication November 17, 1932.

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A good check on seasonal conditions and differences can, of course, be obtained from daily meteorological records. But even with the aid of such records it is exceedingly difficult to evaluate different seasons in relation to their favorable and unfavorable factors for the growth of specific plants. The climatic factors of the environment under which the plant grows have cumulative as well as separate effects on the development of a crop. It is difficult at times to ascribe a certain behavior to any one particular climatic factor. It would indeed be a great aid to field plat work to be able to evaluate the various seasons encountered in relation to plant growth and behavior by one single figure. This would be especially valuable since such experiments usually extend over a period of years. But the climatic factors making up a season are complex, perhaps too much so, to be treated and summarized in such a fashion.

The effects of a certain complex of climatic factors for any given period of time are best recorded by the specific responses on the part of the plant. Records of climatic conditions are indeed of value, but they can be of even greater value if they can be correlated for given periods with direct plant behavior. Due to this it was deemed expedient in working with nursery plats to resort to the use of growth curves for the purpose of recording the development of plants at given intervals.

EXPERIMENTAL WORK

THE GROWTH CURVE

Growth curves of plants may be presented either on the basis of successive weights of the entire plant or separate portions thereof, or on the basis of height. The latter method is most convenient and most readily recorded. When such curves are to be constructed on the weight basis it is necessary to deal with different plants at each weighing, while height data can be obtained from the same plants. The use of weights, since the dry matter content of plants changes throughout the growing season, also entails the labor of reducing all weights to a dry matter basis. Since the data on growth curves are to supplement other data compiled from plat tests, it was thought advisable to use the simplest method available. The construction of growth curves from height data enables the investigator, because of the small amount of time required to make the necessary measurements, to work with a larger number of selections or plants than would be possible by any other method.

The heights of plants were measured at weekly intervals. Measurements were taken during the vegetative phases of growth to the tallest leaves and after heading to the top of the heads, but not to the top of awns as in bearded varieties.

Of the various methods that may be employed in expressing growth in plants, the plotting of successive heights as ordinates against time as abscissas gives the best graphic presentation of occurrences during the various portions of the growing season. When the growth curve is presented in this fashion a logarithmetic curve results. The general slope of this curve is of special significance in its application to crop studies.

MATHEMATICAL FORMULATIONS OF GROWTH CURVES

Gaines and Nevens (2)[3] suggest the possibilities of making use of the constant of Robertson's growth equation, stating that "if the constants have the significance attached to them by Robertson, they should be of value in supplementing the data of final crop yield as customarily used in variety tests, etc." Robertson made use of the formula expressing the course of an autocatalytic monomolecular reaction in his growth equation. Rippel (6) shows graphically how the slopes of growth curves of plants are affected by variations in the magnitudes of the constant "K" used in Robertson's equation. Brody (1) gives a critical summary of proposed equations representing growth rates. The main difficulty encountered in the use of these equations is that the curves produced by them are symmetrical, unless provisions are made to allow for the changing values of the constants used during the different phases of the growth cycle. Actual curves plotted from data obtained in the field deviate from the symmetrical as will be shown in the later part of this paper, due to the reaction of the plants with various climatic and edaphic factors. No doubt various growth equations may be of value for particular investigations, yet demanding one limited or "master" equation to represent the entire course of such a complex process as growth is asking a good deal.

Attempts were made in this investigation to make use of Robertson's growth equation, which as given by Robertson (7) in its simplest form, that is upon integration, is expressed by the formula:

$\text{Log}\,\frac{x}{A - x} = K(t - t_1)$, in which x = the height which has been attained in time t; A = the total amount of growth attained during the cycle; K = a constant, the magnitude of which determines the general slope of the curve; and t_1 = the time at which growth is half completed, the time in days required for the plant to attain half of its final height.

Table 1 gives the values of K in Robertson's growth equation for time t in days from emergence for the various crops and varieties measured in 1932. The great variations in the values of K for the same variety at different times t during the growing season are quite apparent. From this it is evident that the average value of K for the growth curve of any one of the varieties given is to a large degree dependent on the specific time t selected for the calculations of the separate values of K to be averaged.

The same variations for the separate values of K are in evidence for the 1931 crop. These values in the case of Ceres for time t taken at 7, 21, 35, 42, 63, and 77 days after emergence are, respectively, .0343, .0197, .0159, .0233, .0167, and .1139. The average of these values of K is .0373 as compared to an average value of .0534 for the same variety in 1932. The 1931 average value of .0373 would be only .0220 if the last value of t in the series were not taken into consideration.

[3]Reference by number is to "Literature Cited," p. 463.

The differences in the calculated values of K for any variety are so great that but little significance can be attached to the averages of the separate values obtained for different values of t. It is interesting, however, to note, even with the wide dispersion of individual values, that the average values of K given in Table 1 are around .027 for the winter wheat varieties, while the average values for the spring sown cereals fluctuate around .050. The values obtained from the growth curves of the spring sown cereal crops are not greatly affected by either the crop or the variety. This indicates that the type of curves produced by plants with similar habits of growth are more indicative of the seasonal conditions shaping such growth curves than of the genetic differences of the crops or varieties grown. The values of K obtained for the two varieties of flax included differ somewhat from those obtained for the spring sown cereal crops.

TABLE 1.—*Values of K from Robertson's growth equation for time t for the growth curves of crops grown in 1932.*

Crop and variety	Values of t in days					Average value of K
	14	21	42	56	63	
Winter wheat:						
Turkey 144	.0263	.0270	.0371	.0198	.0253	.0271
Kharkof	.0313	.0322	.0453	.0154	.0160	.0280
Spring wheat:						
Ceres	.0419	.0368	.0475	.0693	.0715	.0534
Marquis	.0431	.0381	.0522	.0607	.0549	.0498
Oats:						
Richland	.0426	.0419	.0504	.0799	.0772*	.0586
Silvermine	.0379	.0397	.0391	.0610	.0877*	.0531
Barley:						
Odessa	.0433	.0303	.0511	.1008*	—	.0564
Horn	.0422	.0360	.0387	.0540	.0816	.0505
Flax:						
Bison	.0524	.0548	.0668	.1353*	—	.0773
Linota	.0536	.0566	.0710	.1144*	—	.0764

*Growth complete.

A GRAPHIC METHOD OF ANALYZING THE GROWTH CURVE

Differences in the growth curves of various plants for any season or for a number of years may be analyzed from the standpoints of (a) symmetry shown, (b) maximum height attained, (c) interval of time from emergence to attainment of greatest height, and (d) on the basis of the generalized slope of the curves produced.

A comparison of the plotted growth curves of Turkey 144 wheat for 1931 and 1932 (Fig. 1) shows very decided differences for the two seasons. The curves of Ceres, a spring wheat shown in Fig. 2, for the same two seasons also show marked differences. These growth curves are constructed by plotting the heights of plants in centimeters as ordinates against time in weeks from emergence as abscissas.

It is evident from Figs. 1 and 2 that the growth curves presented are not symmetrical. Those of the abnormal season of 1931 are far less symmetrical than those of the more normal growing season of 1932. The 1931 curves for both the winter and the spring wheats show three definite checks in growth. These checks are brought out

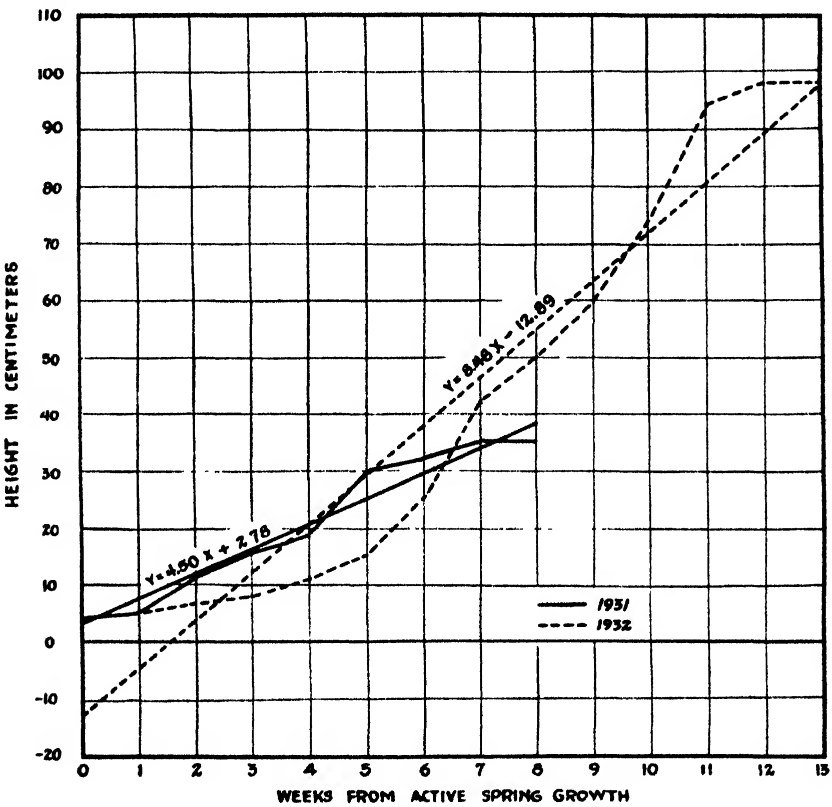

FIG. 1.—Growth curves and straight line trends of such curves of Turkey 144 winter wheat for the seasons of 1931 and 1932.

especially well in the case of the growth curves of Ceres. The set backs in the development of these and other crops were due to untimely freezes and cold weather and in the case of the third check to a combination of low temperature (21° F on May 22) and severe drought. Conditions were so severe that the winter wheat did not recover from the third and last of these checks. The relationship between the shapes of the growth curves of the crops here under consideration and the temperature factor is brought out by a comparison of Figs. 1 and 2 with Fig. 3, which gives the daily minimum temperatures from the middle of April to the end of May for the years of 1931 and 1932.

The growth curves for 1931 and 1932 do not show only differences in symmetry, but also deviations in total height attained and decided

differences in their relative slopes. The maximum height attained by plants in plat tests is readily recorded and is generally incorporated in the field notes.

Nearly all investigators recognize the importance of recording in their field notes the time interval from emergence to such stages in the

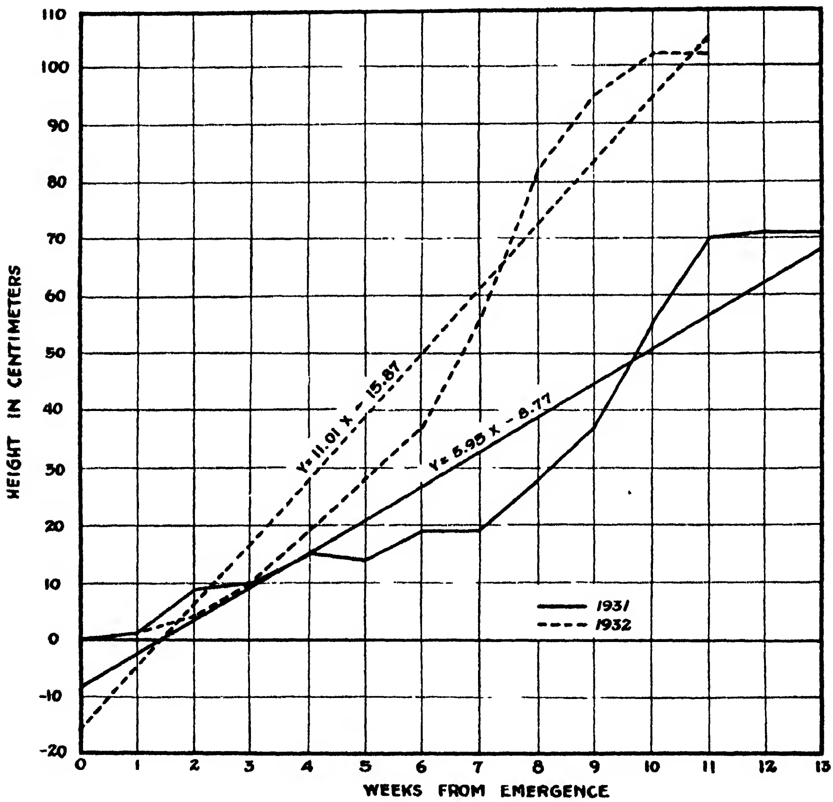

FIG. 2.—Growth curves and straight line trends of such curves of Ceres spring wheat for the seasons of 1931 and 1932.

development of plants dealt with, as heading, flowering, and maturity. Where weekly measurements of plant heights are made, the intervals in days or weeks from emergence to the point where the growth curves attain their maximum heights are readily ascertained. In the cereal crops this time corresponds more or less with the completion of heading.

The relative slope of the growth curve is of great importance in the analysis of final returns. A reliable figure designating the general slope of the growth curve may be used to advantage in the comparison of two or more seasons. As has been pointed out Robertson's K fluctuates too much in value when used on unsymmetrical curves, such as must of necessity be dealt with here, to give a reliable index.

The type of curves encountered, however, may well be fitted to straight line trends either by the method of averages or by the method of least squares. Both of these methods are discussed in detail by Gavett (3). The method of least squares gives the more accurate results, and since it requires but little more time, especially if a com-

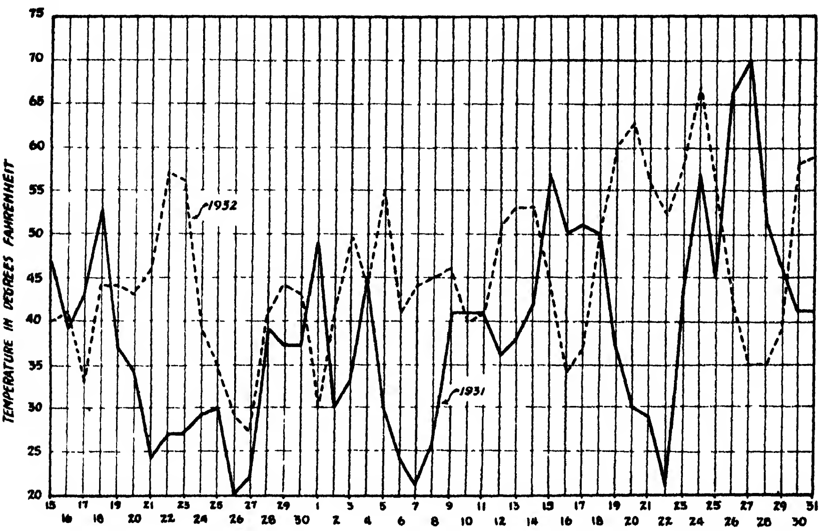

FIG. 3.—Minimum temperatures from the middle of April to the end of May recorded at Brookings, South Dakota, for the years 1931 amd 1932.

puting machine is available, than the method of averages, it is used in this investigation.

In the application of the method of least squares to the curves here under consideration, all x and y values were taken from the point of origin, which in all the curves for the spring sown crops was 0, up to and including the second constant value of the upper asymptote. The employment of the last two constant values of the upper asymptote tends to counterbalance the slow rise of the curve at the lower asymptote. In the case of the winter wheat varieties the points of origin were taken from the time of active spring growth. Table 2 gives the adjustment of the growth data of Horn barley for the season of 1932 to the line of least squares.

Table 3 gives the yields, in bushels per acre, of the crops and varieties measured in 1931 and 1932, as well as the maximum height attained by each, the number of weeks required from emergence to the point of attainment of maximum height, the slope of the line of least squares, and the equation of that line referred to the x and y axes. Of these values the slope of the straight line trend of the curves is of greatest significance to the evaluation of the two seasons. Roughly, the slopes of the least squares lines are almost again as great in 1932 as in 1931. It is interesting to note that these values are very much alike for the respective classes of crops grown. The

TABLE 2.—*Adjustment of the growth data of Horn barley for 1932 to the line of least squares.*

No.	Observed x of weeks from emergence	Observed y Height of plants in cm	Calculated equation of least squares line $y=11.29x-10.54$	Correction to observed y
	0	0	—10.54	—10.54
	1	1	.75	— .25
	2	8	12.04	+ 4.04
	3	18	23.33	+ 5.33
	4	27	34.62	+ 7.62
	5	40	45.91	+ 5.91
	6	55	57.20	+ 2.20
	7	78	68.49	— 9.51
	8	86	79.78	— 6.22
	9	96	91.07	— 4.93
	10	96	102.36	+ 6.36
				31.46–31.45

differences in the values obtained for the three varieties of winter wheat grown in 1931 are affected to some degree by the longer period of time required by Kharkof to attain its maximum height. The values for the varieties of common spring wheat grown in both seasons differ but little even though both early and late maturing and tall and short growing varieties were included. That the slopes of the growth curves of the two durum wheats, Mindum and Algeria, would show some difference was to be expected in view of great differences in the maturity and height of these two varieties. The two varieties of winter wheat measured in 1932 produced very close values, as did also the two varieties of barley and flax. Ceres and Marquis show but small differences in the slopes of their growth curves. Even the two varieties of oats included show no very great differences. Richland, an early maturing, rather low growing variety, showed an average rate of increase in height amounting to 10.92 cm per week, as compared to 12.45 cm per week for Silvermine, a taller growing and later maturing variety.

The growth curve of Turkey 144 showed a slope of only 4.50 in 1931 as against 8.48 in the more favorable season of 1932. These corresponding values for Kharkof were 3.56 and 8.38, respectively. Of the spring sown grains, Ceres was grown in both 1931 and 1932. The slopes of the straight line trends of the growth curves for this variety for the two respective seasons were 5.95 and 11.01. The fact that the growth curves of the spring sown cereal crops exhibited very similar slopes for the respective seasons emphasizes the point previously stated, namely, that the figures designating the slopes of the curves produced may be used to good advantage, if not for the direct evaluation of two or more seasons, then at least to supplement meteorological data of the seasons encountered in the course of particular field plat experiments.

The great similarities in the evaluations of the slopes of the growth curves of crops grown throughout the same part of the season as spring wheat, oats, and barley is not surprising. This similarity is in

TABLE 3.—*Growth data of crops measured in 1931 and 1932.*

Crop and variety	Yield per acre in bu.	Greatest height attained in cm	No. of weeks from emergence to attainment of greatest height*	Slope of line of least squares	Equation of line of least squares referred to the x axis and y axis
		1931			
Winter wheat:					
Turkey 144	2.9	35	7	4.50	y = 4.50x + 2.78
Minturki	8.0	37	7	4.70	y = 4.70x + 2.53
Kharkof	13.7	36	9	3.56	y = 3.56x + 3.84
Common spring wheat:					
Ceres	16.7	71	12	5.95	y = 5.95x - 8.77
Minn. Double Cross	16.1	71	12	5.88	y = 5.88x - 7.51
Quality	18.0	61	11	5.66	y = 5.66x - 5.96
Prelude	9.4	58	11	5.13	y = 5.13x - 5.16
Durum wheat:					
Mindum	20.6	79	12	6.48	y = 6.48x - 7.34
Algeria	16.8	58	10	5.58	y = 5.58x - 2.09
		1932			
Winter wheat:					
Turkey 144	20.2	98	12	8.48	y = 8.48x - 12.89
Kharkof	18.8	94	12	8.38	y = 8.38x - 11.63
Common spring wheat:					
Ceres	20.7	102	10	11.01	y = 11.01x - 15.87
Marquis	18.1	98	10	10.52	y = 10.52x - 14.38
Oats:					
Richland	68.2	90	9	10.92	y = 10.92x - 10.05
Silvermine	50.9	106	9	12.45	y = 12.45x - 12.80
Barley:					
Odessa	40.8	85	8	11.25	y = 11.25x - 10.76
Horn	40.3	96	9	11.29	y = 11.29x - 10.54
Flax:					
Bison	8.4	65	8	8.19	y = 8.19x - 13.27
Linota	7.3	61	8	7.86	y = 7.86x - 11.67

*In the case of winter wheat this refers from the time of active spring growth to attainment of maximum height.

evidence both from straight line trend calculations (Table 3) and from the calculation of Robertson's constant K (Table 1). Klages (4, 5) has called attention to the high degrees of correlation shown by the yields of such spring sown cereal crops, especially in the Great Plains area.

The grain yields of the respective crops grown in 1931 and 1932 listed in Table 3 do not differ as much for the two seasons given as may rightly be expected from the differences shown by their growth curves. The differences in the yields for the seasons of 1931 and 1932 are very pronounced in the case of the winter wheats but are not so great in the case of the spring wheats. Ceres in 1931 yielded 16.7 bushels per acre as compared to 20.7 bushels in 1932. These differences for Marquis were 13.1 as against 18.1, for Richland oats 26.0

and 68.2, for Silvermine oats 12.7 and 50.9, for Odessa barley 25.1 and 40.8, and for Horn barley 21.6 and 40.3 bushels per acre for the seasons of 1931 and 1932, respectively. Growth curves for the oats and barley varieties grown in 1932 are not available for 1931. It may be assumed, in view of the similarity of these crops to spring wheat, that they would have given much the same values as those shown by the spring wheats in 1931, namely, rather low figures for their respective slopes. The differences in the yields of oats and barley for the two seasons are decidedly in favor of the 1932 season. But on the basis of the great differences in the growth curves of the spring wheats for the two seasons, greater differences in yields than those actually produced could rightly have been expected in the case of this crop. It is necessary to keep in mind, however, that growth curves based on height data yield an index of seasonal conditions and differences only up to that portion of the growing season when the maximum height is attained. The season of 1932, as shown by the rather symmetrical and steep growth curves produced, was quite favorable to the development of the crops discussed during the vegetative phases and in the case of the barley and oats practically up to maturity. In the case of the spring wheat, however, the crop was severely damaged by hot dry weather after the flowering period. Due to this condition a complete correlation between growth data and final yield performance cannot be expected in all seasons.

SUMMARY AND CONCLUSIONS

Two years' growth data on cereal crops and flax are presented to show that the construction and analysis of growth curves may yield information that can be used to good advantage to supplement yield data from plat experiments, especially insofar as such curves may furnish an index on the basis of which the different seasons encountered in the course of the experiment may be evaluated.

Growth curves were constructed from data obtained from weekly height measurements of winter wheat, spring wheat, oats, barley, and flax.

The growth curves of the various crops grown were analyzed from the standpoints of (a) symmetry shown, (b) maximum height attained (c) interval of time from emergence to attainment of greatest height, and (d) on the basis of the generalized or average slope of the curves produced.

Attempts were made to evaluate the slopes of the growth curves produced by the employment of Robertson's growth equation. It was found that the differences in the calculated values of K (the constant) in any variety, since all of the curves encountered deviated from the symmetrical, were so great that but little significance could be attached to the averages of the separate values obtained for different values of t (the time factor).

The fitting of the growth data to straight line trends by the method of least squares gave the most reliable and workable means of expressing the general slope of growth curves of crop plants. By the employment of this method the growth curve of Turkey 144 showed

an average slope of 4.50 for the unfavorable growing season of 1931 when it yielded but 2.9 bushels per acre as against a slope of 8.48 and a yield of 20.2 bushels in the more favorable season of 1932. The curve for Ceres, a spring wheat, showed slopes of 5.95 and 11.01 for these same respective seasons.

The fact that the growth curves of all of the spring sown cereal crops measured exhibited very similar slopes for the respective seasons emphasizes the point that the values designating the slopes of the curves produced may be used to good advantage, if not for the direct evaluation of two or more seasons, then at least to supplement meteorological data of the seasons encountered in the course of particular field plat experiments.

Since the compilation of growth data is completed in the cereal crops at or near the heading stage, it cannot provide an index of seasonal conditions during the ripening period, consequently a complete correlation between one value summarizing growth data and shaped especially during the vegetative period of development of the plant and final yield performance cannot be expected in all seasons. Nevertheless, the data presented show rather conclusively that the types of curves produced by plants with similar habits of growth, such as spring sown cereal crops, are more indicative of the seasonal conditions shaping such growth curves, especially those factors determining the slope of these curves, than of the genetic differences of the crops or varieties grown.

The growth curves here dealt with and the equations given for the straight line trends were used strictly to give information to supplement yield data and as a means of expressing the general slope of the curves. They were not and should not be employed for purposes of predicting final yields or ultimate height of plants prior to the completion of growth. The primary object of this investigation was not to clothe the rather unsymmetrical growth curves produced with the dignity of a mathematical formula or to obtain a particularly close fit between the produced curves and an exponential equation involving two or more variables, but rather to express the general slope of these curves in an understandable and practical manner. Mathematically formulated curves, except where provisions are made to allow for the changing values of constants employed for the various phases of the growth cycle, are symmetrical. The processes concerned in organic growth are too complex to yield to a simple master equation. Actual growth curves plotted from data obtained in the field deviate from the symmetrical not so much as resulting from variations in the rates of growth during the different phases of development as to the special reactions of plants to a variety of climatic and edaphic factors. The slopes of such curves are well expressed by straight line trends.

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THE RELIABILITY OF NURSERY TESTS AS SHOWN BY CORRELATED YIELDS FROM NURSERY ROWS AND FIELD PLATS[1]

K. H. W. KLAGES[2]

Nursery trials of cereal crops are usually looked upon as a means of eliminating new strains or varieties and as being preliminary to field plat tests. Since many selections properly replicated can be grown on a small area and since with facilities available to the agronomist such tests can be readily conducted, nursery rod row trials provide an excellent method for not only preliminary testing but for obtaining reliable yield data.

What has been stated above may infer that yield data from nursery tests are less accurate and reliable than results obtained from field plat trials. This need not necessarily be the case. It has been shown by a number of investigators of field plat technic that the variability in the yields of such plats can be reduced by increasing, up to certain limits, the size of plats used—but increased size of plats necessarily entails an increase in the area to be covered by the experiment and in that way not infrequently increases the disturbing influence of soil heterogeneity. The fact that nursery plats can be replicated more readily and that the number of replicates used in these trials is generally greater than in the regular field plat variety tests serves to enhance the reliability of nursery results.

Some measure of the reliability of yield data obtained from rod row nursery tests may be obtained by correlating the yields of varieties included for the same year or period of years in both nursery and field plat tests. Since both rod row and regular field plat trials are made use of in agronomic research, it will be interesting to compare yields obtained from these common types of field tests.

PLAN OF EXPERIMENTAL WORK

For a period of 3 to 4 years varieties of common spring wheat, durum wheat, oats, barley, and flax were included both in the regular variety test plats and nursery trials at Brookings. The regular

[1]Contribution from the Department of Agronomy, South Dakota Agricultural Experiment Station, Brookings, S. Dak. Received for publication November 17, 1932.

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variety tests consisted of triplicate plats, while the nursery was conducted with triplicate rod rows, of which only the center rows were harvested for yields. The nursery plats were replicated three times, that is, four plats of each variety were grown. Due to irregularities in yields resulting from the application of sodium chlorate 2 years previous to the test, it was necessary in 1932 to discard the third repetition of the regular spring wheat variety test; consequently the yield data for wheat of the field plats for that year are based on duplicated plats only. Up to and including the season of 1929, the variety test plats were 1/50 acre in size and were separated by cultivated alleys. Beginning with the season of 1930, the areas of these plats were reduced to 1/60 acre and were conducted with cropped alleys in the manner described by Klages.[3] The field plats in all cases were 132 feet in length.

The number of varieties of each crop included in both the regular variety and nursery tests for the several years of the experiment is shown in Table 3. Such varieties were arranged systematically in the variety test plats but were distributed at random with other varieties and strains tested in the nursery. The total number of varieties and strains grown in the several cereal and flax nurseries from 1929 to 1932 are given in Table 1.

TABLE 1.—*Number of varieties and strains grown in the cereal and flax nurseries at Brookings for the years indicated.*

Crop	1929	1930	1931	1932
Common spring wheat	131	71	71	75
Durum wheat	18	18	18	—
Oats	26	44	76	81
Barley	39	75	80	80
Flax	—	33	34	34

No effort was made to grow the two respective series of plats in close proximity to each other. In some years the variety test plats were removed by more than half a mile from the nursery tests. Neither was any special effort made to plant these two sets of plats at exactly the same time. No doubt the differences in the dates of planting and emergence had some influence on the degrees of correlation shown between the yield data from the two sets of plats. It is an established fact that different varieties react differently towards prevailing climatic factors with variations in their dates of planting or during various stages of development. Evidences of this will be pointed out. Table 2 gives the dates of planting and emergence of each of the crops grown on the variety test and nursery plats for the 4 years of the experiment.

RESULTS

ANNUAL VARIETY TEST AND NURSERY PLAT YIELD CORRELATIONS

Table 3 gives the coefficients of correlation between the variety test plat and nursery yields shown by the varieties of common spring

[3]KLAGES, K. H. W. A modification of Delwiche's system of laying out cereal variety test plots. Jour. Amer. Soc. Agron., 23:186–189. 1931.

TABLE 2.—*Dates of planting and emergence of each of the crops grown in the variety test and nursery plats for the years indicated.*

Crop	1929		1930		1931		1932	
	Variety test plats	Nursery	Variety test plats	Nursery	Variety test plats	Nursery	Variety test plats	Nursery
Date of Planting								
Common spring wheat	Apr. 23	Apr. 17	Apr. 15	Apr. 4	Apr. 6	Apr. 1	Apr. 13	Apr. 22
Durum wheat	Apr. 22	Apr. 19	Apr. 15	Apr. 4	Apr. 7	Apr. 6	—	—
Oats	May 13	Apr. 19	Apr. 22	Apr. 8	Apr. 13	Apr. 1	Apr. 21	Apr. 18
Barley	May 3	Apr. 26	Apr. 24	Apr. 22	Apr. 23	Apr. 8	Apr. 23	Apr. 21
Flax	—	—	May 3	Apr. 15	Apr. 24	Apr. 17	Apr. 28	May 3
Date of Emergence								
Common spring wheat	May 6	Apr. 30	May 1	Apr. 16	Apr. 18	Apr. 13	Apr. 26	May 4
Durum wheat	May 6	Apr. 30	May 3	Apr. 16	Apr. 18	Apr. 15	—	—
Oats	May 25	May 4	May 4	Apr. 23	Apr. 28	Apr. 13	May 3	May 2
Barley	May 15	May 8	May 3	May 3	Apr. 30	Apr. 18	May 6	May 4
Flax	—	—	May 9	Apr. 30	May 4	Apr. 30	May 7	May 10

TABLE 3.—*Number of varieties, n, grown in the variety test and nursery plats and the coefficients of correlation, r, between the yields of each of these crops on the two respective series of plats for the years indicated.*

Crop	1929		1930		1931		1932		Average value of r
	n	r	n	r	n	r	n	r	
Common spring wheat	11	+.7793±.0799	14	+.5692±.1219	14	+.8140±.0608	11	+.7195±.0981	+.7205±.0465
Durum wheat	7	+.7007±.1298	7	+.5339±.1823	7	+.4590±.2013	—	—	+.5645±.1003
Oats	12	+.6219±.1193	14	+.5938±.1168	14	+.7122±.0888	15	+.3203±.1563	+.5620±.0613
Barley	29	+.5160±.0919	29	+.6279±.0759	13	+.7333±.0865	14	+.2043±.1647	+.5429±.0522
Flax	—	—	9	—.0265±.2247	9	+.7043±.1133	9	+.5851±.1479	+.4210±.0972

wheat, durum wheat, oats, barley, and flax grown in these two sets of plats for the years indicated. Positive values, and in most instances positive values of significance, are exhibited in all cases except for the flax data of 1930 where a slight negative correlation is in evidence.

The highest and most consistent correlations are in evidence for the common spring wheat tests. The yields of the common spring wheat varieties obtained from the variety test plats and nursery rows are presented graphically in Fig. 1. For 3 of the 4 years of comparison, the values of r remained above .71. In 1930, the lowest value of .5692 ± .1219 was encountered. The differences in the dates of planting of the wheat nursery and variety test plats were greater, as may be seen from Table 2, in 1930 than in any other season. The differences in the dates of emergence of plants on the variety test plats and nursery were 6, 15, 5, and 8 days, respectively, for the four consecutive seasons of 1928 to 1932. The lower degree of correlation in 1930 may be accounted for by the lack of conformity to the general trend by two varieties, namely, Marquis x Emmer H_{44} and Prelude.

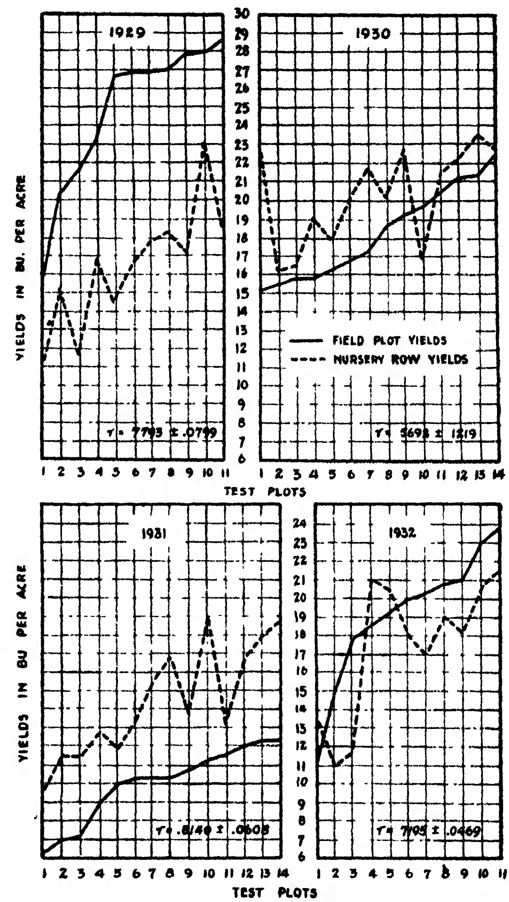

FIG. 1.—Yields of common spring wheats on variety test and nursery plats, arranged in consecutive order from the lowest to the highest yielding variety or the regular variety test plats for each of the four years of comparison.

H_{44} showed a high yield in the nursery and a very low yield in the variety test plats. The difference in the performance of this variety in the two sets of plats can readily be accounted for by the earlier planting date of the nursery. Marquis x Emmer hybrids, such as H_{44} and Hope, are quite susceptible to high temperatures during the post-heading period. This explains the relatively high yields of these varieties in the early planted nursery plats and their much lower yields in the variety test plats planted 11 days later. Prelude, a very

early maturing variety with generally low yielding capacity, was adversely affected by early planting in the nursery but gave a good comparative yield in the variety test plats at the later date of planting.

The yields of durum wheats were compared for but 3 years. Since the number of varieties was small, the probable errors of r are quite high. When the correlation coefficients for 2 of the 3 years are considered in relation to the magnitude of their respective probable errors, they are not large enough to be very significant. A very satisfactory correlation was obtained in 1929, even with the small number of varieties employed.

The values of r between the yields of the two sets of oat plats are large enough to be significant in all years with the exception of 1932. It will be of value at this point to go somewhat into an analysis of the yield data for that season. The average yields of all varieties on the two sets of plats were very much alike, namely, 54.7 for the nursery as compared to 58.8 for the variety test plats. The yields of such early maturing varieties as Richland and Gopher were higher on the nursery than on the variety test plats, while the yields of later maturing types, such as Swedish Select and White Russian, were decidedly lower on the nursery than on the variety test plats. The variety White Russian yielded 58.8 bushels per acre on the variety test and only 21.9 bushels on the nursery plats. The fact that the variety test plats were located on a rather low piece of land where moisture was more abundant than on the higher and drier nursery plats accounts largely for these differences in yields and in the relatively low degree of correlation between the variety test and the nursery plats in 1932. The nursery plats received enough moisture for the production of good yields in the early maturing varieties, but not an amount sufficient to mature properly the late varieties, while on the variety test plats, due to more favorable soil relationships, the moisture supply sufficed for the normal development of the late maturing types.

Fairly constant and in all instances, except for the season of 1932, significant correlations were obtained from the barley yield data. What has been pointed out regarding the great soil differences of the variety test and nursery plats in the 1932 oats tests applies also to the barley tests of that year. All 1932 barley yields were depressed during the later phases of ripening by the extremely high temperatures prevailing at that particular time. The yields of the medium maturing, generally high producing varieties were depressed to a greater extent than those of early maturing types with generally lower yielding capacities. Since more moisture was available to the plants on the variety test plats, varietal differences other than earliness entered more into the final yield determinations on these plats than on the drier nursery plats. There is every reason to believe that higher correlations would have been in evidence for both the oats and barley tests in 1932 except for the great soil differences encountered in these tests and the special seasonal conditions which served to exaggerate these differences.

The 1930 flax nursery and variety test plats gave yield data, as is evident from the value of r = —.0265 ± .2247, that varied independently of each other. The fact that the variety test plats were planted 18 days after the nursery served to make two independent tests and may well account for the lack of correlation between the yields of the two sets of plats. The planting dates in 1931 and 1932 corresponded more closely and fairly good degrees of correlation are in evidence.

The average values of r for the several years of comparison of yield data from the variety test and nursery plats given in Table 3 show significant correlations for all crops, even though only rather moderate degrees of correlation are in evidence for certain crops in some seasons.

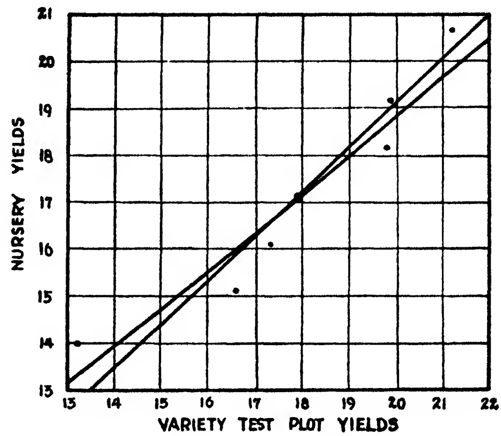

FIG. 2.—Correlation diagram showing relationship between the 4-year average yields of seven varieties of hard red spring wheat on variety test and nursery plats, r = +.9520 ± .0241. The regression lines for x on y and y on x are $\bar{X}$ = 1.07y—0.43 and $\bar{Y}$ = 0.81x + 2.64, respectively.

RELATIONS BETWEEN AVERAGE YIELDS FROM VARIETY TEST AND NURSERY PLATS

Unless a variety or strain has undesirable agronomic characteristics on the basis of which it may be discarded, it is necessary for variety tests to extend over a period of at least 3 and preferably 5 years to yield significant data or before definite judgment may be passed on the several varieties included in the test. Since this is an established fact, it will be well at this time to analyze yield data obtained over a period of years from variety test and nursery plats from the standpoint of degrees of correlation existing between the average yields from the two series of plats.

Table 4 gives the degrees of correlation between the average yields of variety test and nursery plats for periods of from 2 to 4 years. High and very significant values of r were obtained in all cases of 3- and 4-year average yields from the two sets of plats. A very high correlation of r = .9520 ± .0241 was obtained between the 4-year average yields of seven varieties of spring wheat on the nursery and variety test plats. A dot diagram of this correlation is shown in Fig. 2. Four-year average yields of 10 varieties of oats gave the high correlation of r = .9065 ± .0380. The 3-year averages of seven varieties of durum from the two sets of plats gave a correlation of r = .8416 ± .0744.

TABLE 4.—*Degrees of correlation between the average yields of variety test and nursery plats for the number of varieties and years indicated.*

Crop	Average yields for number of years	Years of averages used	Number of varieties in both sets of plats	r between average yields from variety test and nursery plats
Common spring wheat	3	1929–31	11	$+.8833 \pm .0447$
Common spring wheat	3	1930–32	9	$+.8918 \pm .0460$
Common spring wheat	4	1929–32	7	$+.9520 \pm .0241$
Durum wheat	3	1929–31	7	$+.8416 \pm .0744$
Oats	4	1929–32	10	$+.9065 \pm .0380$
Barley	2	1929–30	29	$+.6495 \pm .0724$
Flax	2	1931–32	9	$+.6235 \pm .1374$

Only 2 years of results are given for barley and flax. Significant correlations are in evidence for both of these crops. For two successive years 29 varieties of barley were grown in both the variety test

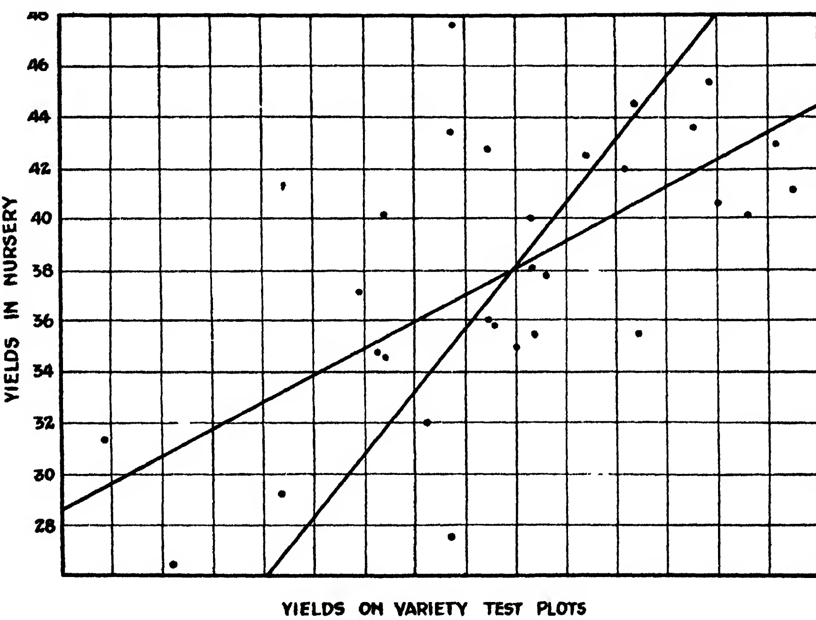

FIG. 3.—Correlation diagram showing relationship between the 2-year average yields of 29 varieties of barley on variety test and nursery plats, $r = +.6495 \pm .0724$. Regression lines for x on y and y on x are $\bar{X} = 0.81y + 3.04$ and $\bar{Y} = 0.53x + 20.12$, respectively.

and nursery plats. The degree of correlation shown by the average yields of this rather large number of varieties is shown diagrammatically in Fig. 3. Since in the case of the flax tests the dates of planting in the first year of comparison of the yield from the two sets of plats were so great as to result in two independent tests, only 2-year average yields are used for this crop. The correlations shown by

the barley and flax were r = .6495 ± .0724 and r = .6235 ± .1374, respectively.

RELATIVE RANK OF VARIETIES ON THE BASIS OF PERFORMANCE IN THE VARIETY TEST AND NURSERY PLATS

Other factors being equal, the all-important value to be derived from variety testing work is a criterion of the relative yielding abilities of the varieties grown under comparable conditions for a period of years. So far the yield data obtained from the two sets of plats under consideration have been analyzed by the degrees of correlation between them. It will be interesting and of value to compare the ranking of the various types tested on the field plats and in the nursery. This is done in Table 5. The average yields for the periods indicated were arranged in consecutive order from the highest down to the lowest on the variety test plats and the corresponding rank position given for the nursery yields.

It will be observed from Table 5 that the average yields of the seven varieties of common spring wheat tested for a period of 4 years in the variety test and nursery plats assume in both series of plats the same relative position The 3-year average yields of 11 varieties of common spring wheat, tested from 1929 to 1931, fall, with some minor shifting, into the same general position in both sets of plats. For the 3-year period of 1930 to 1932 an exception is found in the common spring wheat tests, insofar as the variety ranking in fifth place in the variety test plats assumes the first place in the nursery. This, however, is not so great a lack of alignment as may appear on first inspection. The average yield of this apparently misplaced variety is but 2.10 bushels per acre less than that of the variety occupying first place and 4.40 bushels above the variety falling into the last place in the series. The durum wheat, oats, and flax varieties show, with some minor modifications, much the same ranking in both series of plats.

TABLE 5.—*Rank agreement of corresponding varieties in the variety test and nursery plats for the average yields of the crops and periods of time indicated.*

Rank in variety test plats	Rank of corresponding variety in the nursery plats					
	Common spring wheat			Durum wheat, 3-yr. av. yields, 1929–31	Oats, 4-yr. av. yields, 1929–32	Flax, 2-yr. av. yields, 1931–32
	4-yr. av. yield, 1929–32	3-yr. av. yield, 1929–31	3-yr. av. yield, 1930–32			
1	1	1	2	3	2	1
2	2	2	3	1	1	2
3	3	4	5	2	3	3
4	4	3	4	5	5	9
5	5	7	1	4	8	5
6	6	5	7	6	6	7
7	7	6	6	7	7	8
8		8	9		9	4
9		9	8		4	6
10		11			10	
11		10				

SUMMARY AND CONCLUSIONS

Varieties of common spring wheat, durum wheat, oats, barley, and flax were grown for periods of 3 and 4 years in both regular variety test plats and nursery rows. Yield data obtained from these two sets of plats were compared from the standpoints of degrees of correlation between them and on the basis of rank agreement.

Rather significant correlations were found between the yields of regular variety test and nursery plats. While the values of the coefficients of correlation found for most seasons were perhaps not high enough to justify an outright recommendation for the entire substitution of the triplicated nursery row method of testing in favor of the employment of the regular variety test plats of 1/50 to 1/60 of an acre, they show that very accurate yield data can be obtained by the use of nursery plats.

The 4-year average yields of seven varieties of common spring wheat from variety test and nursery plats showed a correlation of $r = .9520 \pm .0241$, and an identical ranking in the two sets of plats. Similar correlations of the yields of 10 varieties of oats gave a value of $r = .9065 \pm .0380$ with good rank agreement.

The values of the correlation coefficients for four separate seasons ranged in common spring wheat from $.5692 \pm .1219$ to $.8140 \pm .0608$, with an average value of $.7205 \pm .0465$; in oats from $.3202 \pm .1563$ to $.7122 \pm .0888$, with an average of $.5620 \pm .0613$; and in barley from $.2943 \pm .1647$ to $.7333 \pm .0865$, with an average of $.5429 \pm .0512$. Three years yield data of durum wheat showed correlations ranging from $.4590 \pm .2013$ to $.7007 \pm .1298$ with an average value of $.5645 \pm .1003$. The yields between the flax variety test plats and nursery showed a slight negative correlation of $-.0265 \pm .2247$ in 1930 when there was a difference of 18 days between the planting dates of the nursery and the variety test plats. In 1931, the value of $r = .7042 \pm .1133$ resulted from the correlation of the yields of the two sets of flax plats.

No doubt the relationships between the yields of the regular variety test and nursery plats would have been even greater than indicated by the figures cited above had it been possible to have had the two sets of plats adjacent to each other in all seasons instead as in most years of the comparison at some distance and not infrequently under somewhat different soil conditions. Nevertheless the results indicate that a great deal of significance can be attached to yield data from properly conducted nursery tests.

A SIMPLE AND RAPID CHEMICAL TEST ON PLANT MATERIAL AS AN AID IN DETERMINING POTASSIUM NEEDS[1]

S. F. THORNTON[2]

In this paper it is desired to give a progress report of our experiences in testing crop plants for their relative potassium content as an aid in determining potassium needs. The test has been developed as a supplementary aid in interpreting and confirming the results of fertility plats, soils tests, and observed plant deficiency symptoms.

It is recognized that many factors influence the ability of plants to obtain nutrients from the soil, and through the use of numerous soil tests considerable progress has been made in their study. In recent years much interest has centered around the use of chemical tests on the plants themselves. This appears to offer some advantages, and, in combination with other tests, may serve as a satisfactory guide in more definitely determining the needs of farm crops for fertilizers.

Chemical analysis of the soil, whether partial or complete, is concerned more with potential fertility than with actual productiveness as measured by crop production. As aptly stated by Fraps (5)[3], "The capacity of a soil to supply plant food is only one of a group of factors which determines how much plant food can be taken up by the crop or what use can be made of it."

One of the most reliable aids in recognizing potassium deficiencies has been the physical symptoms displayed by growing plants. For the corn plant the first external symptoms are the marginal firing of the older leaves accompanied by a fading of the green color between the veins. Severely deficient plants usually have a weak root development and a tendency to die early and bear ears with soft, misshapen cobs and chaffy grains on prematurely broken shanks. In general, it may be said that, in contrast to nitrogen and phosphorus deficient plants where the tendency is to form undersized but completely developed plants, potassium deficient plants often develop normally at first but die prematurely without seed formation. The effect of potassium deficiency upon external appearance varies greatly with different plants but is nearly always associated with a spotting or a curling of the leaves.

In 1926, Hoffer (7) proposed and developed a chemical field test as an aid in confirning observed symptoms of potassium deficiencies in corn plants. This work established the inverse relation between the supply of potassium available to the plant and the accumulation of iron in the nodal tissues. Hoffer also showed that the potassium content of the corn plant varies widely and that this variation reflects the supply in the soil to which the plant has access.

[1]Contribution from the State Chemist's Department, Purdue University Agricultural Experiment Station, Lafayette, Ind. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication November 18, 1932.

[2]Assistant Chemist.

[3]Reference by number is to "Literature Cited," p. 481.

Later, Gilbert and Hardin (6) suggested the use of the composition of the plant sap as an indicator of the available nutrient supply in the soil. The potassium content of the saps of corn plants was found to vary with the fertilizer treatments.

In a similar manner McCool and Weldon (8) have shown that the chemical composition of the expressed saps of various crop plants is markedly affected by fertilizer treatment.

MacGillivray, *et al.* (9) used the platinum chloride test to study potassium deficiencies in tomatoes. Thin cross sections of leaf petioles were allowed to remain in a 10% solution of platinum chloride for 2 days and then examined with the aid of a microscope. The relative abundance of potassium platinic chloride crystals was taken as an indication of the nutrient level in the plant.

Pettinger (10) found a nearly perfect correlation between the potassium content of the plant sap and potassium fertilization. The sap from plants grown on plats which had received either muriate of potash or manure contained from 2 to 16 times as much potassium as did the sap from plants receiving no potassium fertilization.

A number of rapid methods for determining potassium in soils and plant materials have been proposed (1, 2, 3, 4, 11). Little work has been done towards standardizing any of the tests on plant material so that the results may be interpreted directly in terms of potassium needs. At present there appears to be need for a method, sufficiently simple and rapid for use as a field test, to give reliable indications of potassium deficiencies.

The writer has developed from the numerous methods to be found in the literature a simplified procedure for estimating the relative potassium content of plant material. Interpretation of the results of this test in terms of potassium needs has been determined through work on plants from a large number of plats, the fertilizer and yield histories of which are known accurately. This procedure is based upon the extraction of the soluble potassium and its precipitation as the cobalt nitrite under conditions carefully worked out to cover the range found to be most significant in determining potassium deficiencies. Such conditions give only a partial precipitation and are looked upon as the most important factor in determining the effectiveness of the test. It has been found necessary to establish two different sets of conditions for precipitation, one for general farm crops and another for crops like tobacco which have an unusually high potassium content and are usually grown at a level of fertility higher than can be profitably maintained for less intensively cultivated crops.

THE METHOD

Reagents.—1. Dissolve 150 grams of sodium nitrite in 1,000 cc of distilled water.

2. Dissolve 5 grams of sodium cobaltinitrite and 30 grams of sodium nitrite in separate portions of distilled water, mix, add 5 cc of glacial acetic acid, and make to 100 cc. Allow to stand several days before using.

3. To 100 cc of reagent 1 add 5 cc of reagent 2.
4. Ethyl alcohol (95%).
5. Dissolve 1 gram of potassium chloride in 100 cc of reagent 1.

Procedure.—With general farm crops place approximately 1/4 gram of finely cut plant material in a glass vial, graduated for both 10 cc and 15 cc contents, fill to the 10 cc mark with reagent 3, shake vigorously, fill to the 15 cc mark with reagent 4, shake, and allow to stand 3 to 5 minutes. With tobacco and similar crops having a high potassium content omit reagent 4 and use the entire 15 cc of reagent 3. Compare with the prepared standards, taking into consideration the combined effects of the density of the precipitate in suspension and the color remaining in solution. Experience with the test renders the use of standards less necessary. For field work color charts may be substituted for the standards.

Standards.—Temporary standards may be prepared by substituting reagent 5 for the plant material. The table below shows for such standards the numerical values, the amounts of reagent 5 required, the density of the precipitate obtained, and the interpretation in terms of potassium deficiency.

Number	Reagent 5	Amount of precipitate	Potassium supply
0	0.0 cc	None	Very deficient
1	0.2 cc	Trace	Very deficient
2	0.4 cc	Light	Moderately deficient
3	0.6 cc	Medium	Doubtful
4	0.8 cc	Heavy	Sufficient
5	1.0 cc	Very heavy	Abundant

The numbers are arbitrarily assigned values for convenience in recording the results. The interpretation in terms of potash supply is based on profitable response under general farming conditions. In field work it is usually sufficient to classify the results as "Deficient," "Doubtful," and "Sufficient," without attempting to make the more detailed classification listed above.

Sampling.—It is obvious that a single plant may fail to give a true picture of an entire field. Samples should be taken from a number of plants representing the average condition of the area. Often six or eight plants will be sufficient, but a larger number should be sampled whenever this seems desirable. The entire sample may be composited and a single test made.

Different parts of plants give different results and certain parts have been found to be more reliable indicators of potassium supply than others. The following list of a few farm crops gives the parts upon which the test has been most successfully used:

Corn—base of leaf at ear node.
Wheat, oats, barley, rye—base of leaf near middle of stalk.
Potatoes—main stem near ground.
Alfalfa, clover, soybeans—tips of main stems.
Tobacco—mid-rib at base of leaf.
Grasses—base of leaves.

EXPERIMENTAL

To correlate the results of the test with actual field yields and responses a large number of tests have been made under conditions where the fertilizer and yield histories are known accurately. The work has been largely confined to corn, but a limited number of tests have been made on other plants. The following tables give the results of the test on a number of the experimental soil fertility fields of the Purdue University Agricultural Experiment Station. As the 1932 yields were not yet available, it was considered advisable to report data for the average of a period of years and also for the single year of 1931.

TABLE 1.—*Results of potash test on corn plants from fertility plats, Bedford, Ind.*

Plat No.	Fertilizer treatment*	Potash test		Yield of corn in bu.†	
		Aug. 3	Sept. 15	1917–30	1931
1	L	3	2	22.6	44.2
2	LP	2	0	39.2	66.9
3	LPK	4	1	42.8	81.5
4	LNPK	4	2	42.2	73.7
5	L	2	0	24.4	46.4
6	LNPK+residues	4	4	44.8	79.6
7	LPK+residues	4	2	44.7	86.9
8	LP+residues	3	2	44.5	90.7
9	L	2	2	25.5	45.8
10	L+residues	3	2	26.5	53.3
11	Residues	3	2	23.3	40.1
12	NPK	3	2	38.1	65.5
13	L	1	3	23.3	40.3
14	O	3	3	19.9	33.6
15	M	4	4	35.3	59.4
16	LM	4	5	39.7	74.7
17	L	1	0	24.3	49.6
18	LMP	4	3	49.1	89.3
19	LMPK	4	4	49.4	98.4
20	LMNPK	4	3	47.2	88.8
21	L	1	1	22.5	43.1

*L = 3 tons ground limestone in 1917, P = 72 lbs. P_2O_5, K = 24 lbs. K_2O, N = 12 lbs. nitrogen per acre per rotation, M = manure equal to produce removed, O = no treatment.

†From the records of the Agronomy Department.

DISCUSSION OF RESULTS

The soil in the Bedford fertility field (Table 1) is an acid silt loam (pH 5.4) which has shown a marked phosphorus deficiency but on which the response to potassium fertilizers has been small up to the last few years. However, 1931 yield data show a pronounced response to potassium fertilizers. The results of the potash test under the Aug. 3 column show a good correlation with the fertilizer treatments as shown by the low values for L and LP plats and the higher values when the treatment has included crop residues, potassium fertilizers, or manure. No effect of lime on potassium availability is evident. Results obtained on Sept. 15 are often somewhat lower than those for the earlier date. This is especially true on those plats where the

TABLE 2.—*Results of potash test on corn plants from fertility plats, Lafayette, Ind.*

Plat No.	Fertilizer treatment*	Potash test			Yield of corn in bu.†	
		June 7	Aug. 10	Sept. 19	1915–30	1931
601	M	4	4	3	60.8	61.9
602	M+S.P.— 72 lbs. P_2O_5	3	4	3	65.1	68.0
603	M+R.P.—288 lbs. P_2O_5	3	4	4	64.4	64.9
604	M	3	4	4	64.5	64.2
605	M+S.P.— 48 lbs. P_2O_5	3	4	4	65.7	62.8
606	M+R.P.—192 lbs. P_2O_5	3	4	3	64.7	61.4
607	M	3	4	4	65.3	68.2
608	M+S P.—24 lbs. P_2O_5	4	4	4	65.5	67.0
609	M+R.P.—96 lbs. P_2O_5	4	4	4	65.1	69.8
610	M	4	4	4	63.3	67.3
611	M+St. B.—48 lbs. P_2O_5	3	4	5	62.4	65.3
612	M+B.S.—48 lbs. P_2O_5	3	4	3	62.7	62.6
613	M	4	4	3	60.4	62.8
614	N+S.P.— 48 lbs. P_2O_5	0	0	0	44.2	38.6
615	N+R.P.—192 lbs. P_2O_5	0	0	1	40.1	36.7
616	O	2	2	0	38.2	40.1
617	NK+S.P.— 48 lbs. P_2O_5	3	1	0	52.6	66.0
618	NK+R.P.—192 lbs. P_2O_5	3	3	1	52.6	68.6
619	M	4	4	3	61.0	67.0
620	M+1 ton R.P.‡	3	4	3	60.7	69.2
621	M+½ ton S.P.‡	3	3	3	61.0	63.5
622	M	3	4	4	60.5	60.6

*S.P. = superphosphate, R.P. = rock phosphate, St.B. = steamed bone meal, B.S. = basic slag, O = no treatment, M = 5.1 tons manure per acre, K = 50 lbs. K_2O, N = 12 lbs. nitrogen per acre per rotation.

†From the records of the Agronomy Department.

‡Applied in 1915 and 1924 only.

potassium application was small and appears to have been insufficient to carry the plants to maturity properly.

The results reported in Table 2 represent a Miami or Crosby silt loam in the higher portions and a Clyde or Brookston silt loam in the depressions. These soils have shown no appreciable responses to any treatment in addition to the basic treatment of manure. In agreement with this fact the potassium tests are high on all manure plats. However, on plats 614 and 615 which have received nitrogen and phosphorus only, the values are very low, corresponding to the low yields.

The North Vernon fertility series (Table 3) is a very acid silt loam (pH 4.8) which has shown a pronounced response to both phosphorus and potassium fertilizers. Values for the potash test on plats which have received neither manure nor potassium fertilizers are very low and increase with the fertilizer treatments to give a very good correlation with the yield responses.

The Wanatah fertility plats (Table 4) are on a Newton fine sandy loam, a very acid, dark-colored soil. Yield data show a pronounced response to potassium fertilizers and, during the earlier period, to lime. This is clearly indicated by the potash test results for both soybeans and corn.

Table 5 represents a non-acid muck soil, very deficient in potas-

sium. This deficiency is reflected in the data given for both corn and potatoes.

With the Vincennes fertility series (Table 6) the yield data show an appreciable response to potassium fertilizers and manure. This

TABLE 3.—*Results of potash test on corn plants from fertility plats, North Vernon, Ind.*

Plat No.	Fertilizer treatment*	Potash test		Yield of corn in bu.†	
		Aug. 3	Sept. 15	1921–30	1931
1	O	1	1	22.5	38.9
2	L	1	1	36.7	46.2
3	L+residues	1	2	41.3	59.2
4	LP+residues	1	2	51.2	66.7
5	LPK+residues	4	4	55.5	72.3
6	L	1	1	39.2	49.7
7	LNPK+residues	4	4	58.1	80.6
8	LMNPK	4	4	67.4	89.4
9	LMPK	4	3	66.4	96.7
10	L	2	2	42.9	52.7
11	LMP	4	4	66.0	90.6
12	LM+R.P.	4	4	63.8	92.1
13	LM	4	3	57.8	89.5
14	L	2	1	43.2	54.1
15	M	4	3	48.5	82.1
16	O	1	1	29.6	43.5
17	NPK	3	3	45.0	66.2
18	L	1	0	42.9	60.7
19	LP	0	0	51.0	70.6
20	LPK	3	4	56.8	77.7
21	LNPK	3	3	57.2	72.1
22	L	1	2	40.5	49.8
23	LNPK	4	4	55.8	72.1
24	LMNK	4	3	56.6	86.3
25	LMNK+Tr. Sup.‡	4	4	62.3	90.5
26	L	0	0	40.0	49.7
27	LMNK+Tr. Sup.+Gyp.‡	4	4	64.0	80.7
28	LMNK+Gyp.‡	4	4	53.2	86.7
29	LMNK+1 ton R.P.+Gyp‡	4	3	62.7	89.1
30	L	2	2	40.3	58.2
31	LMNK+1 ton R.P.‡	4	4	60.9	91.0
32	LMNK+½ ton S.P.‡	4	3	66.9	86.7
33	MNK+1 ton R.P.‡	4	3	60.5	86.4
34	L	2	1	40.4	59.7
35	O	2	1	27.1	52.1

*R.P. =640 lbs. rock phosphate, Tr. Sup. =380 lbs. treble superphosphate, Gyp. =600 lbs. gypsum, S.P. =superphosphate, L=3 tons ground limestone in 1921, M=manure, O=no treatment, P=48 lbs. P_2O_5, K=32 lbs. K_2O, N=4 lbs. nitrogen per acre per rotation.

†From the records of the Agronomy Department.

‡Applied in 1921 and 1927 only.

agrees, in large measure, with the results of the potash test which, for manure especially, has given higher values for potassium additions. Here again the values for the later test date are lower with the exception of manure which has continued to show a rather high value. This series suffered somewhat from lack of sufficient moisture during the past summer.

TABLE 4.—*Results of potash test on plants from fertility plats, Wanatah, Ind.*

Plat No.	Fertilizer treatment*	Potash test		Yield of corn in bu.†	
		Soybeans, Aug. 16	Corn, Aug. 16	1920–30	1931
1	O	0	1	8.1	42.9
2	L	0	0	16.2	37.4
3	LPK+Ca.Sil	3	4	26.0	49.1
4	LNPK	3	4	23.8	51.7
5	LPK	4	3	25.0	51.7
6	L	1	0	15.9	36.3
7	LK+R.P.	3	3	23.8	50.9
8	LK	3	3	23.8	51.1
9	LP	1	1	19.6	44.6
10	L	1	0	16.7	34.9
11	O	0	1	10.0	43.7
12	M	3	3	14.5	45.1
13	LM	1	2	27.2	47.7
14	L	0	1	17.6	41.4
15	LM+R.P.	4	4	28.2	56.9
16	LMP	2	2	25.9	50.0
17	LMPK	3	3	26.6	51.4
18	L	0	1	15.7	32.9
19	LK+½ ton S.P.‡	2	4	27.2	40.0
20	LK+1 ton R.P.‡	3	3	26.3	43.7
21	LK+1 ton R.P.+Gyp.‡	4	4	28.0	45.4
22	L	0	2	19.5	29.6
23	LK+Gyp.‡	3	3	22.8	41.7
24	LK+Tr. S.P.+Gyp.‡	4	4	26.3	43.7
25	LK+Tr. S.P.‡	4	3	26.4	43.4
26	O	1	2	6.8	36.6
27	L	2	1	13.7	24.0

*L = 4 tons ground limestone in 1920, M = manure equal to produce removed, R.P. = 640 lbs. 30% rock phosphate, S.P. = superphosphate, Ca.Sil. = 1 ton calcium silicate applied in 1920, Tr. S.P. = 380 lbs. 42% treble superphosphate, Gyp. = 640 lbs. gypsum in 1920 and 1927, O = no treatment, NPK, PK, K & P = 400 lbs. per acre of 2–12–12, 0–12–12, 0–0–12 and 0–12–0 respectively, applied on each corn crop.

†From the records of the Agronomy Department.

‡Phosphates and gypsum applied in 1920 and 1927 only.

TABLE 5.—*Results of potash test on plants from muck fertility plats, Wanatah, Ind.*

Plat No.	Fertilizer treatment	Corn			Potatoes	
		Potash test, Aug. 16	Yield in bushels*		Potash test, Aug. 16	Yield in bushels,* 1925–30
			1925–30	1931		
1	0	0	27.7	22.0	0	58.9
2	600 lbs. 0–0–24	4	37.4	62.6	3	135.6
3	600 lbs. 0–8–24	4	42.6	81.4	3	150.0
4	600 lbs. 0–16–24	3	48.2	79.7	3	137.3
5	0	1	30.8	24.4	0	78.1
6	600 lbs. 0–8–48	4	50.5	82.3	4	173.2
7	Lime+300 lbs. 0–8–24	4	49.4	87.1	3	131.9
8	600 lbs. 0–8–24	4	46.3	74.9	3	121.5
9	0	0	28.8	17.7	1	58.9

*From the records of the Agronomy Department.

TABLE 6.—*Results of potash test on corn plants from fertility plats, Vincennes, Ind.*

Plat No.	Fertilizer treatment*	Potash test		Yield of corn in bu.†	
		Aug. 3	Sept. 15	1925–30	1931
1	L	1	0	29.5	39.0
2	LP	2	1	33.5	45.1
3	LPK	3	0	42.6	46.8
4	L	2	0	37.1	42.0
5	LNPK	3	2	44.3	45.7
6	NPK	3	1	42.6	48.9
7	L	2	0	31.4	45.0
8	O	1	0	31.4	33.1
9	M	4	3	51.1	50.9
10	L	2	0	36.3	37.0
11	LM	4	3	51.3	52.3
12	LMP	4	3	55.8	49.4
13	L	1	0	34.8	42.4
14	LMPK	4	3	58.6	52.3
15	LMNPK	4	4	57.4	48.1
16	L	2	0	32.8	33.5

*O = no treatment, M = manure equal to produce removed, L = 2 tons ground limestone in 1925, P = 60 lbs. P_2O_5, K = 30 lbs. K_2O, N = 10 lbs. nitrogen per acre per rotation.

†From the records of the Agronomy Department.

Table 7 shows the effect of tile drainage on results of a potash test. This indicates the possibilities of the test in the study of factors affecting the available potassium supply and illustrates the possibility that analysis of the soil may fail to give a true picture of the ability of plants to obtain nutrients from it. The soil is the same in both cases. The only variable appears to be the ability of the roots to penetrate and draw upon the food supply contained in the subsoil. It will be noted that only on those plats where a large amount of potassium has been added in the form of manure is a high test given by plants growing between the tile lines.

TABLE 7.—*Effect of drainage on potash test with corn plants.*

Plat No.	Fertilizer treatment	Potash test	
		Over tile	Between tile
404	Residues	3	1
407	O	3	0
408	Manure	3	3
410	Residues	3	0
518	O	3	1
519	Lime+manure	4	3
520	Lime	3	0
521	Lime+2–12–6	2	1
614	NP	3	0
615	NP	4	1
616	O	2	0
617	NPK	2	0
618	NPK	2	0
619	Manure	4	4

SUMMARY

During the past few years much interest has centered around the use of the plant itself as an indicator of nutrient deficiencies. This appears to offer several advantages.

A simple and rapid procedure for estimating the relative potassium content of plant tissues has been found to be a very valuable aid in determining the needs of farm crops for potassium fertilizers. This procedure is based upon the extraction of the soluble potassium, its precipitation as the cobalt nitrite under definitely specified conditions, and its estimation by comparison with prepared standards or color charts.

Interpretation of results of the test in terms of potassium supply is based on work on a large number of plats whose fertilizer and yield histories are definitely known. Data are given for corn, potatoes, and soybeans from several of the experimental soil fertility farms of the Purdue University Agricultural Experiment Station. A good correlation is shown between results of the test and fertilizer treatments and yield responses.

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INHERITANCE OF AWN DEVELOPMENT IN SONORA WHEAT CROSSES[1]

K. S. QUISENBERRY and J. ALLEN CLARK[2]

The inheritance of awnedness in wheat has been studied for many years in different crosses and by several workers. Most of the work has been research to determine the genetic behavior of the factors controlling awn development. In addition to determining the mode of inheritance there is a practical side to the problem, as in some sections of the United States increasing length of awns is known to be associated with increased yield. On the other hand, where hand labor is still used in harvesting, awnless varieties usually are preferred by growers. It is desirable, therefore, to have some knowledge of the manner of segregation to be expected from crosses between varieties differing in length of awns.

PREVIOUS WORK WITH SONORA

In 1918, Babcock and Collins (1)[3] advised their students to "avoid the use of Sonora wheat in hybridizing to produce material for elementary class use. Some of its characters behave differently from similar characters of other varieties."

Gericke (4) reported in 1923 that Sonora wheat when grown in tap water produced 7 plants in 100 with awns 1½ to 2 inches long, whereas none of the plants grown in the soil produced other than rudimentary organs 2/8 to 3/8 inch long, common to the variety. He states: "tap water, and perhaps also the effect of the then prevailing climatic complex, therefore, served as a means to permit expression of a character in wheat that did not appear under the usual conditions in which this variety is grown."

Love and Craig (5), in a brief note, reported that when Sonora was crossed with other awnless varieties the F_1 was awnless, whereas awned and partly awned types appeared in the F_2 and later generations. No data were presented, but segregation was stated to approach a 15:1 ratio for awnless and awned types, which indicated that Sonora carries a factor for awns. In crosses between Sonora and awned varieties they reported a preponderance of awned plants. A complete report of their extensive work with Sonora has not yet been published.

From these reports it appears that Sonora differs from other awnless or awnleted wheats in its genetic behavior for awn development.

MATERIALS AND METHODS

In the studies reported herein Sonora was crossed with Quality, Supreme, and Reliance. Sonora has short incurving awnlets that

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication November 18, 1932.

[2]Agronomist and Senior Agronomist, respectively.

[3]Reference by number is to "Literature Cited," p. 492.

develop not only on the lemmas of the tip florets but also on the lemmas of florets farther down on the spike. Sonora is classed as weakly awnleted or 3— (2). The awnlets of Quality differ from those of Sonora in that they are confined to the tip of the spike, are a little longer, and are not incurving. Quality is classed as strongly awnleted or 3+ (Fig. 1). Both wheats are designated as awnleted to dis-

FIG. 1.—Sonora and Quality together with awn types obtained in hybrid populations of Sonora x Quality.

tinguish them from awnless (class 1). Supreme has no awn development and is classed as awnless (class 1). Reliance is classed as awned (class 5).

The F_1 plants were grown in a greenhouse at the Arlington Experiment Farm, Rosslyn, Va., or in the field either at Davis, Calif., or Bozeman, Mont. All of the F_2 and F_3 generation plants were grown in the field at Davis, Calif., or Bozeman, Mont. The method of sowing was to space 70 kernels in a 16-foot row. The mature heads of the individual F_2 plants were cut from the culms, placed in envelopes, and shipped to Washington, D. C., where the notes were taken. Part of the notes on the F_3 were taken in the field by studying the heads on each plant and part in the laboratory by classifying one head taken from each plant in the row.

The plants were placed in five classes, as follows: 1, awnless; 2, apically awnleted; 3, awnleted; 4, short awned; and 5, awned (Fig. 1).

RESULTS

The data obtained from the three crosses, although combined in some tables, are discussed separately.

SONORA X QUALITY

The F_1 plants of this cross between two awnleted (class 3) parents were apically awnleted (class 2), having less awn development than either parent. The F_2 data are presented in Table 1, together with similar data for Sonora x Supreme and for Sonora x Reliance. Reciprocal crosses were grown, but since no differences were obtained the data were combined. Of the F_2 plants 5.0% were awned and 13.2% were awnless; thus types were produced having more and less awn development than the parents.

From 2,090 F_2 plants, 527 were selected for growing in the F_3 generation. The selection was not made at random as it was desired to study the extreme classes more thoroughly than the others. The breeding behavior of the F_3 lines is shown in Table 2, together with the corrected F_2 percentages based on the breeding behavior of these 527 lines.

The F_3 strains are separated into 24 groups, according to breeding behavior. In each case the modal class is indicated by italic figures. Some of the variation may have been due to environment or to minor modifying factors. Those groups that are more nearly alike as to breeding behavior are combined into eight genotypic groups as shown in Tables 2 and 3.

TABLE 1.—*Segregation for awn development in the F_2 generation of Sonora x Quality, Sonora x Supreme, and Sonora x Reliance wheat crosses.*

	Number and percentage of F_2 plants by awn classes					Total
	1, awnless	2, apically awnleted	3, awnleted	4, short awned	5, awned	
			Sonora x Quality			
Number....	276	907	634	169	104	2,090
Percentage	13.2	43.4	30.3	8.1	5.0	100
			Sonora x Supreme			
Number....	57	28	30			115
Percentage	49.6	24.3	26.1			100
			Sonora x Reliance			
Number....		1	31	105	87	224
Percentage		0.4	13.8	47.0	38.8	100

The F_2 generation plants classed as 1 and 2 overlap in their breeding behavior in F_3. Of the class 1, or awnless plants, 49.5% bred true, the remainder segregating. As expected, the class 2 plants had a wide range of segregation since this is the F_1 class. All but 3 of the 77 awned (class 5), plants bred true. In Table 2 is shown the corrected F_2 distribution based on the breeding behavior of the 527 F_3 lines grown. These percentages were obtained by considering the F_3 breeding behavior and the F_2 classification. For example, 276 plants, or 13.2%, of the F_2 population were placed in class 1 and of these only 49.5% proved to have been correctly classed according to the F_3 data. This indicates that only 6.5% rather than 13.2% of the F_2 should

TABLE 2.—*Segregation for awn development in the F_3 generation of a Sonora x Quality wheat cross, in comparison with the parents, grown at Davis, Calif., and Bozeman, Mont., 1926–28.*

Breeding behavior in F_3	Sonora	Awn classes in F_2 and number of strains grown: 1, awnless No.	1, awnless %	2, apically awnleted No.	2, apically awnleted %	3, awnleted No.	3, awnleted %	4, short awned No.	4, short awned %	5, awned No.	5, awned %	Quality	Total F_3 lines	Genotypic group and corrected class		Corrected F_2 percentage	
1		48	49.5	2	1.3								50	I	1	7.1	7.1
1, 2		10	10.3	3	1.9								13	II	2	2.2	
1, 2, 3		15	15.5	4	2.6								19		2	3.2	
1, 2		3	3.1	4	2.6								7		2	1.5	
2				1	.6								1		2	0.3	
1, 2, 3		19	19.6	52	33.4								71		2	17.1	
2, 3		1	1 0	4	2.6								5		2	1.3	25.6
1, 2, 3, 4		1	1.0	8	5.1								9	III	2	2.3	
1, 2, 3, 4, 5				54	34.7	3	2.9						57		2	15.9	
1, 2, 3, 5				1	0.6								1		2	0.3	
2, 3, 4, 5				1	0.6								1		2	0.3	
1, 2, 3, 4, 5				14	9.0	10	9.7						24		2	6.8	
2, 3, 4, 5				1	0.6	6	5.8	3	3.2				10		2	2.3	27.9
1, 2, 3				1	0.6								1	IV	3—	0.3	
2, 3				1	0.6	1	1.0						2		3—	0.5	
3	12			3	1.9	10	9.7						13		3—	3.8	4.6
2, 3, 4						3	2.9						3	V	3+	0.9	
3				2	1.3	14	13.6	1	1.1			16	17		3+	4.8	5.7
3, 5						33	32.1	3	3.2				36	VI	3	10.0	
3, 4, 5						2	1.9	2	2.1				4		3	0.7	10.7
2, 3, 4, 5						3	2.9	9	9.6				12	VII	4	1.6	
3, 4, 5						18	17.5	76	80.8				94		4	11.8	13.4
3, 4, 5										3	3.9		3	VIII	5	0.2	
5										74	96.1		74		5	4.8	5.0
Total	12	97	100	156	100	103	100	94	100	77	100	16	527			100	
Original F_2		276	13.2	907	43.4	634	30.3	169	8.1	104	5.0		2,090			100	

have been placed in class 1. A total of 907 plants, or 43.4%, of the F_2 were placed in class 2, but the F_3 data indicated that 1.3% of these, or 0.6%, of the total F_2 really belonged in class 1. This makes a total of 7.1%, the corrected F_2 percentage of class 1. Similar calculations for the other classes give the corrected data in the last column of Table 2.

Table 3.—*Total number of plants by genotypic groups of F_3 strains of the Sonora x Quality wheat cross and of the parent check rows.*

Genotypic group	Parents and breeding behavior	No. of lines	Number of plants classed as				
			1, awnless	2, apically awnleted	3, awnleted	4, short awned	5, awned
I	Awnless	50	2,055				
II	Segregating for classes 1, 2, 3	116	1,698	2,351	917		
III	Segregating like F_2 for all classes	102	395	1,641	1,349	608	291
IV	Awnleted, like Sonora	16	9	28	598		
	Sonora	12			471		
V	Awnleted, like Quality	20		15	857	15	
	Quality	16			733		
VI	Segregating for classes 3 and 5	40			1,327	58	446
VII	Segregating for classes 3, 4, 5	106		54	1,207	2,274	1,301
VIII	Awned	77			24	35	2,005

The corrected F_2 percentages show 7.1% awnless, 4.6% awnleted like Sonora, 5.7% awnleted like Quality, and 5.0% awned, the remainder being in segregating groups.

In Table 3 are shown the total plant counts for each breeding group. The variation of the character is shown by the data in the table. In the genotypic group II, the segregation is for classes 1, 2, and 3 and theoretically should give counts approximating a 1:2:1 ratio. The totals obtained show too many class 1 and too few class 3 plants. It will also be seen that all the Sonora plants were class 3, while in the lines designated as like Sonora there were 37 plants of a total of 635, which were class 1 and 2. This same type of variation is apparent in genotypic groups V and VIII. These minor variations may be environmental or genetic. It is possible also that some natural crossing took place in the F_2. In general, however, the segregation appears to be controlled by two major genetic factor pairs.

SUPREME X SONORA

The F_1 plants of this cross were apically awnleted or class 2. The F_2 data in Table 1 show that 26.1% of the F_2 plants were awnleted and 73.9% were awnless or apically awnleted.

In Table 4 is shown the breeding behavior of 98 F_3 lines. These are separated into seven groups according to their breeding behavior. Here again there is overlapping in the breeding behavior of various F_2

TABLE 4.—*Segregation for awn development of 98 F_3 strains of the Supreme x Sonora wheat cross in comparison with the parents.*

Breeding behavior in F_3	Supreme	Awn classes in F_2 and number of strains grown						Sonora	Total F_3 lines	Genotypic group and corrected class		Corrected F_2 percentage	
		1, awnless		2, apically awnleted		3, awnleted							
		No.	%	No.	%	No.	%						
1	2	14	28.6						14	I	1	14.2	
1, 2	4	11	22.4	3	11.5				15		1	13.9	28.1
1, 2, 3		24	49.0	17	65.5	2	8.7		42	II	2	42.5	
1, *2*, 3				3	11.5				3		2	2.8	
1, 2, *3*				3	11.5	2	8.7		5		2	5.1	50.4
2, *3*						10	43.5	6	10	III	3	11.3	
3						9	39.1		9		3	10.2	21.5
Total	6	49	100	26	100	23	100	6	98				
Original F_2		57	49.6	28	24.3	30	26.1		115				100

plants, especially those in class 1 and in class 2. There appears to be, however, three genotypic groups, awnless, segregating, and awnleted. According to the corrected F_2 percentages there were 28.1% awnless, 50.4% segregating, and 21.5% awnleted. The total number of plants by genotypic groups is shown in Table 5. The awnless lines were as uniform as the Supreme parent and awnleted lines as uniform as the Sonora parent. The segregating lines showed the same type of segregation as in F_2 in that the largest number of plants fell in the awnless class.

TABLE 5.—*Total number of plants by genotypic groups of the 98 F_3 strains of Sonora x Supreme wheat cross in comparison with the parents.*

Genotypic group	Parents and breeding behavior	Number of F_3 strains	Number of plants classed as		
			1, awnless	2, apically awnleted	3, awnleted
	Supreme	6	225	17	
I	Awnless	28	1,075	70	
II	Segregating for classes 1, 2, and 3	51	1,301	464	529
III	Awnleted	19		58	720
	Sonora	6		79	176

SONORA X RELIANCE

The F_1 plants of this cross were classified as short awned, class 4. The F_2 data are shown in Table 1. The F_2 plants were placed in four classes, *viz.*, 2, 3, 4, and 5. In class 5, awned, there were 38.8%, and in class 3, awnleted, there were only 14.2%.

The breeding behavior in F_3 is shown in Table 6. The F_3 strains were separated into 10 groups based on breeding behavior. These were classified into three distinct genotypic groups, awnleted, segregating, and awned. The corrected F_2 percentages show only 7.9% awnleted, 66.6% segregating, and 25.5% awned. This is a different type of segregation than is commonly found in awnleted x awned crosses in that usually as many homozygous awnleted as awned strains are recovered. It will be seen from the data in Table 7 that in the segregating lines many more awned than awnleted plants were recovered. The totals do not approach the 1:2:1 ratio for awnleted, short awned, and awned, which is usually obtained in awnleted x awned crosses. However, the data show a good fit to a 3:1 ratio for partly awned to awned.

DISCUSSION

The data for the Sonora x Quality cross show that the F_3 lines could be roughly placed in eight breeding groups, and that the corrected F_2 ratio suggests a two major factor difference. Since both parents are awnleted and both awnless and awned segregates were obtained, it must be assumed that each parent possesses one dominant factor pair for the awnless condition. The following factorial setup gives a possible explanation.

TABLE 6.—*Segregation for awn development of 100 F_3 strains of the Sonora x Reliance wheat cross in comparison with the parents.*

Breeding behavior in the F_3 generation	Sonora	Awn classes in F_2 and number of strains grown								Reliance	Total F_3 lines	Genotypic group and corrected class		Corrected F_2 percentage	
		2, apically awnleted		3, awnleted		4, short awned		5, awned							
		No.	%	No.	%	No.	%	No.	%						
2,3	6	1	100	3	9.7						4	IV	3	1.7	
3				2	6.5						2		3	0.9	
2,3,4				3	9.7						3		3	1.3	
3,4				9	29.0						9		3	4.0	7.9
3,4				1	3.2						1	VII	4	0.4	
3,4,5				13	41.9	8	24.2				21		4	17.3	
4,5						1	3.0				1		4	1.4	
3,4,5						18	54.6	9	25.7		27		4	35.6	
4,5						6	18.2	3	8.6		9		4	11.9	66.6
5								23	65.7	6	23	VIII	5	25.5	25.5
Total	6	1	100	31	100	33	100	35	100	6	100				
Original F_2		1	0.4	31	13.8	105	47.0	87	38.8		224				

TABLE 7.—*Total number of plants by genotypic groups of the 100 F_3 strains of the Sonora x Reliance wheat cross in comparison with the parents.*

Genotypic group	Parents and breeding behavior	No. of lines	Number of plants classed as			
			2, apically awnleted	3, awnleted	4, short awned	5, awned
	Sonora	6	90	162		
IV	Awnleted	18	71	723	90	
VII	Segregating 3, 4, and 5	59		150	1,024	1,355
VIII	Awned	23				853
	Reliance	6				236

Sonora (awnleted) = aaBB Quality (awnleted) = AAbb

F_1 (apically awnleted) = AaBb

The F_2 genotypes and their F_3 breeding behavior would be as follows:

F_2 Genotype	F_2 Phenotypic class	Breeding behavior in F_3	Genotypic group	Theoretical percentage
AABB	1	Awnless	I	6.25
AABb AaBB	2	Segregating for class 1, 2, and 3	II	25.00
AaBb	2	Segregating like F_2 for classes 1, 2, 3, 4, and 5	III	25.00
aaBB	3	Awnleted, like Sonora	IV	6.25
AAbb	3	Awnleted, like Quality	V	6.25
Aabb	3	Segregating for classes 3 and 5	VI	12.50
aaBb	4	Segregating for classes 3, 4, and 5	VII	12.50
aabb	5	Awned	VIII	6.25

This segregation is summarized in the following diagram in which the figures within the squares refer to the awn classes:

	1 AA	2 Aa	1 aa
1 BB	1	2	3—
2 Bb	2	2	3+
1 bb	3+	4	5

If the population studied in F_3 is corrected to a random sample by applying the corrected F_2 percentages to 527, the number of F_3 strains grown, it is possible to test the agreement between observed and calculated numbers by the goodness-of-fit test. The value of $P = 0.32$ thus obtained indicates that the agreement is fairly close. It is concluded that the interaction of two major genetic factor pairs explains the principal segregation obtained. As already pointed out,

there are additional variations in awn development that may be due to environment or to minor genetic modifying factors. The inheritance described is similar to that reported by Clark, *et al.* (2) in crosses between awnless and awned wheats.

The variation reported by Gericke (4) might be explained on the basis of a natural cross between Sonora and some other awnleted variety, the F_1 being apically awnleted and not detected in the Sonora, whereas in F_2 6.25% of the plants would be awned.

In the Supreme x Sonora cross the corrected F_2 percentages indicated a single-factor difference. Applying these percentages to the 98 F_3 strains grown and comparing the obtained with the calculated numbers for a 1:2:1 ratio, the agreement $P=0.65$ is close. Assuming that Sonora has the factorial composition of aaBB, Supreme would be AABB, or the same as the awnless segregates of the Sonora x Quality cross.

TABLE 8.—*Breeding behavior of F_3 lines of Sonora x Quality, Supreme x Sonora, and Sonora x Reliance wheat crosses compared with calculated ratios by the goodness of fit method.*

Genotypic groups	Sonora x Quality		Supreme x Sonora		Sonora x Reliance	
	Observed numbers	Calculated numbers	Observed numbers	Calculated numbers	Observed numbers	Calculated numbers
I	37	33	32	29		
II	135	131	58	57		
III	147	132				
IV	24	33	25	29	8	25
V	30	33				
VI	57	66				
VII	71	66			67	50
VIII	26	33			25	25
Total	527	527	115	115	100	100
Value of P	0.32		0.65		Very low	

In the Sonora x Reliance cross it was shown that approximately 25% of the strains were awned, indicating a single major factor difference. There were, however, too few awnleted strains and too many segregating strains for a good fit to a 1:2:1 ratio. It was also shown that in the segregating group there was an excess of awned plants which is different from the usual type of segregation found in awnleted x awned crosses such as reported by Clark and Quisenberry (3). The factorial composition of Reliance is assumed to be aabb.

The goodness of fit for the three crosses is shown in Table 8. Only for the Sonora x Reliance cross was a poor fit obtained. The percentage of awnleted segregates obtained in this cross is suggestive of a 2-factor difference, but if such were the case true-breeding (class 4), short-awned strains should have been produced. None of these was obtained. The excess of awned plants in the segregating strains is suggestive of a dominant factor for the awned character. To prove such a dominance it would be necessary to cross two awned varieties

and produce true-breeding awnleted strains. So far as known this has not been done.

To have better tested the factorial setup proposed for the Sonora x Quality cross, Sonora should have been crossed with the awnless and awned segregates rather than with other varieties. If an additional factor or factors are operating in the Sonora x Reliance cross, it can not be stated from which parent these factors came, since Reliance might not be of the same genotype as the awned segregates from the Quality x Sonora cross.

SUMMARY

From a cross between Sonora and Quality, two awnleted wheats, a complete range of segregation was obtained in F_2 from awnless to awned. In the F_3 generation there were obtained true-breeding awnless and awned strains as well as strains awnleted like both parents. There was also a wide range of segregating groups. It is assumed that Sonora contains the genetic factors aaBB and Quality contains the factors AAbb, whereas awnless segregates are AABB and awned ones are aabb.

From a Supreme x Sonora (awnless) cross the segregations in F_2 and F_3 indicated a single genetic factor difference. Supreme is assumed to be AABB.

The segregation in a Sonora x Reliance cross could not be completely explained by a single major factor difference. Reliance is assumed to be aabb, although a minor genetic factor appears to be operating.

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NOTE

A RAPID METHOD OF PLANTING SMALL FIELD PLATS OF ROW CROPS

Several years ago at Texas Substation No. 12, Chillicothe, Texas, it became necessary to enlarge those phases of the work that required the planting of plant-to-row progenies of cotton and sorghums and to refine the field experiments with all crops by decreasing the size of plats and increasing the number of replications. The principal difficulty encountered was the increased number of times seed had to be changed and planter hoppers had to be emptied and cleaned in the course of planting the tests. After a year or two in which various efforts were made to overcome this difficulty, a method of planting was adopted which has been found to economize time and labor but which requires no additional equipment.

During the planting season of 1932 there were 2,130 head-to-row plantings of sorghums and 400 plant-to-row plantings of cotton. There were 1,566 test plats of sorghums varying in size from 1/600 to 1/42 acre and 200 1/84 and 1/42 acre plats of cotton. These figures make a total of 4,296 plats. These plantings occupied 52 acres and were made in 64 hours by three men and a team of two mules.

An ordinary two-row-press-wheel corn and cotton planter is used, Seats are supplied for three men, two to drop the seed and one to drive the team and handle the planter. The planter hoppers are removed, and each of the two men who are planting is equipped with a piece of down-spout rainwater pipe of proper length to reach from the operator's lap to the planter seed-spout. The seed is distributed by hand through these spouts. Seed that has previously been put in bags or packets is arranged in a box placed convenient to the hands of the two men who are planting. In planting cotton delinted seed must be used. After a little practice, seed can be distributed with considerable uniformity and desirable rates of planting approximated.

The use of this method of planting saves a great deal of time because the pause between the planting of one plat and the next is only long enough to allow for the disposal of the sack or packet from which seed has been planted and the picking up of another. Much more time than this is consumed in the usual method of emptying and cleaning hoppers, and still more time is saved if frequent changes in planter plates are required as is sometimes the case in planting variety tests.

In addition, this method allows the use of a larger part of an area for experimental purposes than is sometimes possible otherwise. Alleyways between series of plats may be reduced to a minimum because planting may easily stop or start within the space of a few inches. The width of the alleyway may, therefore, be determined by conditions other than that of the space required to turn a team and planter.

A press-wheel planter may be used in lister furrows if the land is prepared for planting by listing with covering plows attached a few hours previous to the actual planting. Enough time should elapse

between the two operations to allow the loose soil in the furrows to dry sufficiently so that packing or baking will be avoided.—J. R. QUINBY, *Texas Agricultural Experiment Station, Chillicothe, Texas*, and J. C. STEPHENS, *Bureau of Plant Industry, U. S. Dept. of Agriculture.*

BOOK REVIEWS

AGRICULTURAL SYSTEMS OF MIDDLE EUROPE: A SYMPOSIUM

Edited by O. S. Morgan. New York: Macmillan Co. XIX+405 pages, illus. 1933. $5.

While this substantial volume will probably appeal most to the economist and teacher, it will also find a place in the library of the agronomist who would keep informed on the development of the agriculture of Europe as having a direct bearing on the well being of the American farmer. In a foreword to the volume, former Secretary of Agriculture Arthur M. Hyde emphasizes this aspect of the book when he says, "The time has long since passed when the American farmer could afford to ignore what farmers in other parts of the world were doing. American agriculture is not a separate but an integral part of the world's economic system, and it is always deeply affected by financial, industrial, and social conditions both at home and abroad." He might have added that the American agricultural scientist must also have a fair perspective of world agriculture if he is to give the proper direction and interpretation to his work.

Dr. O. S. Morgan, Professor of Agriculture, Columbia University, in his capacity as editor of the symposium has attempted to make the work more of the nature of a source book for agriculturists, economists, politicians, and others than a textbook for class room work, although it is to be used for collateral reading in graduate courses in agricultural economics in Columbia University. "This book attempts to contribute authentic agricultural economic summaries of national agricultural programs and policies of Central European states," says Dr. Morgan in the preface. "It is the combined result of the labors of busy agricultural officials and the editor. It is hardly the composite voice of the respective nationals, but it represents fairly, with a minimum of political and nationalistic effusion, the voices of authoritative spokesmen." It is hoped that the present work will be the forerunner of a series of books on the agriculture of the countries represented.

The chapter headings and the contributors in each case are as follows: I. The Austrian Agrarian Policy, by Leopold Hennet and Anton Steden; II. Bulgarian Agriculture, J. S. Molloff; III. Czechoslovak Agriculture, Sc. T. Vladislav Brdlík; IV. The Agricultural Policy of Greece, Georges Servakis and C. Pertountzi; V. Agriculture and the Agricultural Economic Policy of Hungary, Iván Edgar Nagy; VI. Polish Agriculture, Waclaw Ponikowski and Victor Lesniewski; VII. Aspects of Rumanian Agriculture, A. Frundianescu and G.

Ionescu-Sisesti; VIII. The Economic Position and Future of Yugoslavian Agriculture, Velimir N. Stoykovitch.

It is the hope of the editor of this symposium that it may in some measure give American agricultural leaders a fair working knowledge of foreign agricultural systems. (J. D. L.)

A TEXTBOOK OF GEOLOGY: PART II. HISTORICAL GEOLOGY

By Charles Schuchert and Carl O. Dunbar. New York: John Wiley & Sons, Inc. VII + 551 pages, illus. Ed. 3. 1933. $4.

This book, now in its third edition, is Part II of a *Textbook of Geology*, written for colleges and universities. Part I deals with physical geology. To so uninteresting a title as "Historical Geology," the written pages scarcely keep step. They are so well written, so easily read, and so full of interesting facts that they become fascinating

The authors present a history of the formation of the earth, told in a dynamic way. They begin with astronomy and end with man. Stratigraphic descriptions are associated with a vivid history of the times, including the climatic changes, the animal life, the plant life, and the relation to present economics and history. The result is that one visualizes the periods and epochs in vivid pictures, not as a mere chronological arrangement of events.

Teachers of agriculture, and agronomy in particular, will see possibilities in it as a background for their students. It only re-emphasizes the importance of information of this kind as the basis for an understanding of soils and plant and animal distribution.

The first 80 pages are devoted to the tools of geology, including a discussion of evolution, the interpretation of fossil records, the table and length of geologic time, and the origin of the earth. Then come 300 pages of interesting chronological treatment of periods in the earth's formation, followed by 100 pages dealing with the physical history of the Cenozoic Era, Glaciation in the Pleistocene, the History of Life, and the Geologic History of Man. At the end of the book, in an appendix of 42 pages, is a discussion of animal and plant phyla to supply any needed information to those unfamiliar with the life discussed in various periods through the book. (H. B. T.)

PLANTS USEFUL TO MAN

By W. W. Robbins and Francis Ramaley. Philadelphia: P. Blakiston's Sons & Co., Inc. VII + 428 pages, illus. 1933. $3.

This book is based in large part upon *Botany of Crop Plants* by the senior author, which treats of the history and geography, botany, structure, culture, manufacture, and uses of the more important crop plants of North America. The present work contains additional chapters on useful forms of the lower plant groups, namely, thallophytes, bryophytes, pteridophytes, and gymnosperms; on the palm and banana families; on ornamental plants; on spices and tropical fruits; on tea, coffee, and chocolate; on medicinal plants; and on in-

dustrial products of vegetable origin. The result is a concise account of the more important plants of use to man throughout the world.

It is especially valuable as a supplement to courses in botany in high schools and colleges, and as such will be found helpful to teachers, both in supplying useful information for presentation to students and as collateral reading. It will be found helpful also to those in geography, economics, and agriculture, and such others who desire a background of knowledge of the world's commercial plants. (H. B. T.)

MORPHOLOGY AND CLASSIFICATION OF GERMAN WHEATS

By John Voss. Mitteilungen Biol. Reichanstalt, 45:3–112, illus. 1933.

This paper has two parts—general and special. In the general part, 23 winter wheats and 5 spring wheats are described, approximately 25 different characters including those of embryo, seedling, leaf, spike, kernel, etc., being used. The special part presents keys for the most important wheats of Germany. With these keys it is possible to identify 156 varieties of *T. vulgare*. These 156 varieties are placed in 8 different groups for the spring wheats and in 21 groups for the winter wheats. Following the keys, a detailed description of each of 105 varieties is given, and this, in turn, is followed by an alphabetical index which gives the number of the figure, the page of the detailed description, and its number in the group. Thirty-two plates make up a total of 95 figures which illustrate important characters of most of the 156 varieties. (A. M. S.)

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 | AUGUST, 1933 | No. 8

INHERITANCE OF STEM-RUST REACTION IN WHEAT[1]

J. ALLEN CLARK and H. B. HUMPHREY[2]

Most varieties of wheat are susceptible to stem rust, *Puccinia graminis tritici* Eriks and Henn. Heavy losses from this disease created a demand for new varieties of hard red spring wheat resistant to or immune from it Breeding for resistance in the past has been difficult. During the earlier years the most available resistant wheats were durums, and crosses between durum and common wheats resulted in sterility and linkage of durum characters with resistance. The discovery in 1919 of resistance in Kota, a common wheat, removed these difficulties. This resistance was a step forward but was not strong enough to eliminate all possibility of loss. Moreover, the inheritance of resistance, although recessive, is complicated, as relatively few and in some cases none of the hybrid plants are as resistant as the resistant parent. The most successful accomplishment in breeding for resistance is the development of Ceres, selected by L. R. Waldron at the North Dakota Experiment Station from a Marquis-Kota cross. Ceres was grown on fully 5,000,000 acres in 1932.

Two new varieties, Hope and H-44, developed by E. S. McFadden from a cross of Marquis wheat and emmer are nearly immune in the mature-plant stage from all the physiologic forms of stem rust to which they have been subjected. This is important in itself, but even more important is the fact that this near-immune reaction is a new character. No sterility is involved in crosses of these and other common wheats and inheritance is such that large numbers of nearly rust-free plants and strains are obtained in hybrid populations. If there are no unsurmountable linkage relations carried over from

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. The inheritance experiments herein reported have been conducted at the Northern Great Plains Field Station, Mandan, N. Dak., and the Langdon Substation, Langdon, N. Dak. E. R. Ausemus assisted in the experiments at Mandan until 1929, when he was succeeded by V. C. Hubbard. Glenn S. Smith has assisted in the experiments at Langdon in cooperation with the North Dakota Agricultural Experiment Station, Fargo, N. Dak. Received for publication November 18, 1932.

[2]Senior Agronomist and Principal Pathologist, respectively.

emmer in Hope and H-44, future breeding for control of the disease will be less difficult.

In the varieties now available there are three types of reaction to stem rust, *viz.*, (a) susceptible (50 to 100% infection) typified by Marquis, Supreme, Power, and Reward; (b) resistant (5 to 60% infection) typified by Kota and Ceres; and (c) near-immune (0 to 5% infection) typified by Hope and H-44. The inheritance of these three rust reactions has been studied in hybrids.

PREVIOUS STUDIES OF HOPE AND H-44 CROSSES

Clark and Ausemus (1)[3] pointed out that in the F_1 and F_2 generations of crosses with Hope, practical or near immunity was inherited as a dominant character, whereas resistance, as in Ceres, was inherited as a recessive character. The dominance in both cases was imperfect or incomplete. The F_1 plants of Hope crosses had a trace of rust. In the F_2 generations there was a piling up or a preponderance of the plants toward the zero, or rust-free, end of the distribution. This was thought to be important because it seemed inherently different from the resistance that, in crosses with susceptible varieties, had a normal or intermediate distribution or else a preponderance of plants at the susceptible end of the distribution. This resistance reaction had furnished little and in some crosses no resistant material for practical plant breeding. Ceres was developed from one of only three resistant selections in an F_2 population.

In 1928, at the annual meeting of the American Society of Agronomy, Clark and Ausemus[4] presented F_3 data on host reaction to stem rust in three crosses, including Hope and Ceres. In crosses of Hope with Marquis and Reliance, it was shown that in the mature-plant stage there were near-immune, resistant, and susceptible strains that bred true. There were also four segregating groups. After a genetic study of the F_2 and F_3 generations of these crosses, the results were explained on the basis of a two-factor difference. Phenotypic ratios for the near-immune, segregating and resistant, and susceptible groups were approximately 4:11:1. A genotypic ratio of 4:2:4:2:1:2:1 also was suggested for seven breeding groups. In a Hope x Ceres cross, however, only a single-factor difference was shown, or a 1:3 ratio for the near-immune to the combined segregating and resistant groups.

During or since this time Goulden, *et al.* (2) reported that in a cross of H-44 x Marquis the mature-plant reaction in the field was controlled by a single pair of genetic factors. Neatby and Goulden (3) in a later study on a Hope x Marquis cross, concluded that two complementary factors are involved. In the same publication they reported that "crosses between Reward and Hope and between Reward and H-44 reveal a factor in Reward capable of inhibiting the action of the Hope and H-44 factors for resistance. Results in these crosses also support the conclusion that the H-44 factor for

[3]Reference by number is to "Literature Cited," p. 511.

[4]CLARK, J. A., and AUSEMUS, E. R. Inheritance of immunity from black stem rust, yield, and protein content in Hope wheat crosses with susceptible and resistant varieties. Washington, D. C., 1928. [Mimeographed, p. 8.]

resistance is governed by a single factor pair, and the Hope resistance by at least two pairs." Quisenberry (4) found in an H-44 x Minhardi cross that mature-plant reaction in the field could not be explained on the basis of a single genetic factor.

FURTHER EXPERIMENTS

Further studies have been conducted at the Northern Great Plains Field Station, Mandan, N. Dak., and at the Langdon Substation, Langdon, N. Dak., under conditions of light and heavy stem-rust infection.

MATERIALS AND METHODS

The parent varieties used in the experiments were the near-immune varieties Hope and H-44, the resistant variety Ceres, and the susceptible varieties Marquis, Reliance, Supreme, Power, and Reward.

Methods were as follows: The hybrid seeds were spaced 3 inches apart in rod rows 1 foot apart. Bulk seed of parent checks was sown in rows, separating the crosses in the F_2 generation. For the F_3 generation selected populations of the plants in the various frequency classes of the F_2 were grown whenever possible. This permitted growing 100% of the extreme classes and gave more complete and accurate data on the F_3 generation. When no rust notes were obtained in F_2, a random rather than a selected sample was grown in F_3. The F_3 strains were sown 3 inches apart in single rod rows, 70 kernels to the row. The parent varieties were sown in the same manner, alternating every tenth row. The plants were pulled when ripe and immediately classified for rust infection.

In all crosses studied the rust reaction was quantitative, there being no sharply defined categories. Plants were classified according to the amount of stem rust in the following frequency classes: 0, 2, 10, 20, 30, 40, 50, etc. These frequencies are 10% class centers with the exception of the first two. The 0 class includes those plants or strains having no infection, or those that average less than 0.4%; the 2% class those plants that have a trace of rust and strains averaging 0.5 to 4.4%; the 10% class those averaging from 4.5 to 14.4%, etc. The breeding behavior of the F_3 strains is determined by the distribution in these frequencies and by the average infection and standard deviation computed from the frequencies. Summaries of the F_2 data and the average F_3 data in similar or smaller frequencies and corrected F_2 distributions, as well as of the average infection and standard deviation of each strain in comparison with the parents, are made possible. These data all facilitate a more accurate genetic interpretation of the results. It is recognized that interpretation is difficult because inherent reactions are affected by environmental influences on both the host plant and the pathogen. It is recognized also that there are no genetic factors for rust reaction, as such, but that there are factors that control morphologic or physiologic responses of the plant, which in turn determine rust infection. Freedom from rust is not traceable to any ability of the host to prevent entry by the rust organism but rather to inability of the rust to develop and show more than a mere trace of infection.

EXPERIMENTAL RESULTS

In Table 1 is presented a summary of the results obtained from crosses studied in the F_3 generation in 1928 and 1931. The range of the parents is shown by lines above the data of each cross with an x indicating their average. The frequencies here used are 5%, with the 0 frequency including strains averaging 0 to 0.4%, the 3% frequency from 0.5 to 5.4%, etc.

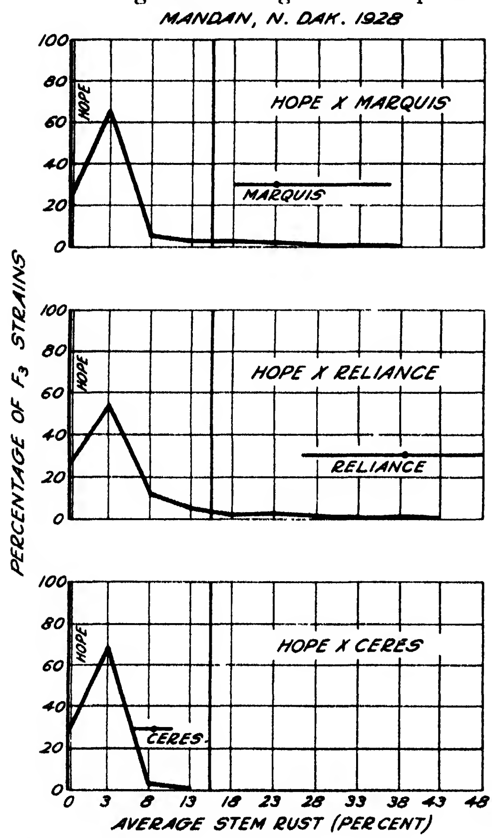

FIG. 1.—Frequency distribution for stem-rust reaction of three wheat crosses and the range and average of the parents at Mandan, N. Dak., 1928.

The data show an imperfect dominance for near immunity in the Hope and H-44 crosses in the case of both susceptible and resistant varieties. In Ceres x Power, the one resistant x susceptible cross, the reaction is intermediate. The Hope x Marquis and Hope x Reliance crosses show about 25% of the corrected F_2 population to be nearly immune, like the Hope parent, whereas at the recessive end of the distribution, or within the range of the Marquis and Reliance parents less than 6.25% are susceptible (Fig. 1). This indicates the presence of two genetic-factor pairs. In the crosses with Supreme and Power the inheritance appears more complicated in that there is a much smaller percentage of near-immune strains and only a very small percentage of susceptible ones, or none so susceptible as the susceptible parent. This indicates that instead of two genetic factors there may be three or more. The dominance is not greatly different, however, as the modal class is in the 3% frequency.

The Hope x Reward cross may be more complicated in its genetic makeup, as only 2.1% of the F_3 strains were in the zero-frequency class. In this experiment, however, one of the Hope parent checks averaged as much as 1.4% of rust and all averaged 1.0%, or high enough to fall in the 3% class. A total of 23.4% of the population may therefore be as rust free as the Hope parent. At the other extreme, however, not one of 94 F_3 strains was so susceptible as Reward, although 24.4% were in the susceptible range. That more than a

Table 1.—*Stem-rust infection of wheat crosses, combining the near-immune, resistant, and susceptible reactions, studied in the F_3 generation at Mandan and Langdon, N. Dak., 1928 and 1931.*

Cross	F_3 strains (No.)	Station	Year	Average stem-rust classes and percentage of F_3 strains: 0	3	8	13	18	23	28	33	38	43	48	53	Average
Near-Immune x Susceptible																
Hope x Marquis	132	Mandan	1928	23.3	63.5	6.4	2.8	2.0	1.3	0.0	0.7					2.9
Hope x Reliance	80	Mandan	1928	25.8	53.4	11.2	5.0	1.1	1.3	1.1	0.0	1.1				5.7
Hope x Supreme	94	Mandan	1931	9.6	43.6	35.1	8.5	2.1	0.0	1.1						5.9
H-44 x Supreme	114	Mandan	1931	4.4	52.6	26.3	9.6	3.5	1.8	0.9	0.0	0.9				6.6
Hope x Power	100	Mandan	1931	11.8	63.6	18.0	2.9	1.7	0.0	1.0	1.0					4.6
Hope x Reward	94	Langdon	1931	2.1	21.3	29.8	22.4	10.6	6.4	3.2	2.1	2.1				11.7
Near-Immune x Resistant																
Hope x Ceres	132	Mandan	1928	27.9	69.3	2.3										2.4
H-44 x Ceres	107	Mandan	1931	15.0	61.7	17.5	4.7	0.9								3.4
Resistant x Susceptible																
Ceres x Power	90	Mandan	1931			1.3	4.5	19.8	22.2	24.7	16.7	6.5	2.1	2.2		26.3

single factor is concerned is proved by the fact that homozygous intermediate strains and several types of segregation were obtained. In this experiment the susceptibility of Reward was not dominant nor did it inhibit the reaction of Hope, as reported by Neatby and Goulden (3). In the cases in which Hope and H-44 were both crossed with Supreme and Ceres there is evidence that Hope is more potent than H-44 in transmitting near immunity from rust.

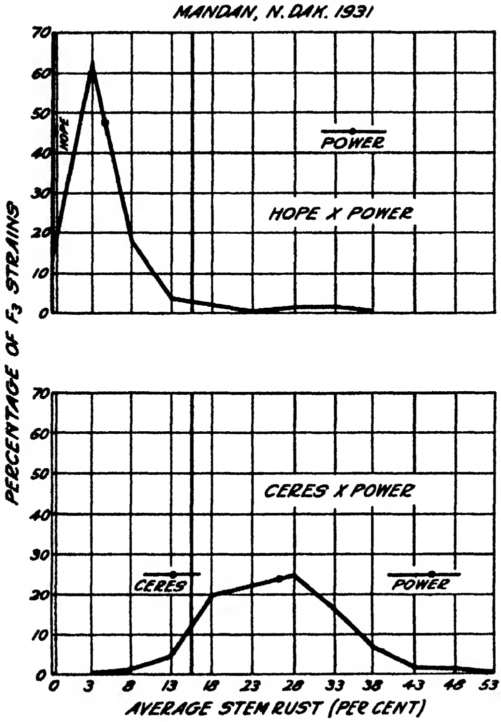

FIG. 2.—Frequency distribution for stem-rust reaction of two wheat crosses, together with the range and average of the parents at Mandan, N. Dak., 1931.

The data for the Hope x Ceres and the H-44 x Ceres crosses suggest a simpler inheritance for the former. While only 2.3% of the strains of Hope x Ceres average as much rust as the Ceres parent, there was little or no evidence of more than one type of segregation. The results were thus interpreted[5] on a single-factor difference. The H-44 x Ceres cross, however, suggests the possibility of a two-factor difference, with transgressive segregation for greater infection.

The Hope x Power cross (Fig. 2), in comparison with the Ceres x Power cross, best illustrates the principal point brought out in this paper, namely, that the near-immune reaction of Hope is a new character and differs inherently from the resistant reaction of Ceres. The difference is comparable to such organographic characters of wheat as awnless, awnleted, and awned spikes; white, brown, and black glumes; and white, red, and purple kernels. The writers feel that this distinct Mendelian character difference in rust reaction is a more logical basis on which to establish the terminology for rust reactions than are overlapping pathological differences.

That pathological reactions overlap is shown by the data for the Hope x Reward and Ceres x Power crosses (Table 1). Such overlapping occurs more often as the amount of infection increases. Under these conditions the difference between the resistant Ceres and the susceptible Marquis sometimes is not great, and overlapping occurs frequently.

[5]See footnote 4.

THE H-44 X CERES CROSS IN 1932

Conditions at the Langdon, N. Dak., station are favorable for heavy rust infection, especially when seeding is delayed one to two weeks later than usual. During the season of 1932, an F_3 of the cross H-44 x Ceres was grown from late seeding at Langdon, in order to test the possible difference in potency and genotypic constitution of Hope and H-44.

Data on the stem-rust infection on the F_2 plants and parents of the H-44 x Ceres cross and the varieties Hope and Marquis, grown in 1931 at Langdon, are presented in Table 2. These data show that, on the average, Ceres rusted 30.3% and Marquis 46.9%. Overlapping occurred in the 40% class. Twenty-four out of 61 plants of the H-44 parent were rust free, making the average 1.2% of infection. Under similar conditions 33 out of 51 plants of Hope were rust free, the average being 0.7% of infection.

TABLE 2.—*Stem-rust infection on F_2 plants and parents of the H-44 x Ceres cross and of Hope and Marquis, grown at Langdon, N. Dak., 1931.*

Variety and cross	Stem rust classes and number of plants								Total	Average
	0	2	10	20	30	40	50	60		
H-44	24	37							61	1.2
H-44 x Ceres	11	180	135	64	24	9	1		424	9.7
Percentage	2.6	42.5	31.8	15.1	5.7	2.1	0.2		100	
Ceres				2	55	4			61	30.3
Hope	33	18							51	0.7
Marquis						13	16	3	32	46.9

The same dominant inheritance as in previous crosses under light infection is shown with 45.1% of the F_2 population as rust free as H-44. The hybrids averaged 9.7% of rust. This infection of the hybrids and parents is about three times that obtained from the same cross at Mandan in 1931.

A selected sample was grown in the F_3. Among 102 F_3 strains, progenies of all 11 rust-free F_2 plants were grown, as well as progenies of the 10 F_2 plants classed as having 40% or more rust. Random samples of the other four classes were grown. The parent varieties and Hope and Marquis were included as checks. The data obtained in the F_3 are summarized in Table 3, and the F_2 percentage distribution, based on 424 plants, is corrected on the basis of the breeding behavior of the 102 F_3 strains. The corrected F_2 percentages are obtained by adding the percentages that each class in F_3 makes up of the original percentage in F_2.

In 1932, Ceres averaged 54.6% and Marquis 84.4% of rust infection, whereas H-44 and Hope had actual averages of but 0.1% and 0.2%, respectively. Both Ceres and Marquis developed more infection than in 1931, while Hope and H-44 showed less. The ranks of the latter are reversed in the two years, but the difference is not significant. There were almost no late tillers on Hope or H-44 plants in 1932, which partly explains their lower average. The rust pustules, when

present, were very narrow slits on normal culms. The fact that Hope is about two days later than H-44 may be the cause of reversal in rank under the heavier infection.

There is a high correlation ($+0.87 \pm 0.02$) between the F_2 plant infection and the average infection of the 102 F_3 strains, which is important from a plant-breeding standpoint. This shows that the classification is reliable and that the reactions for each year were not affected much by the different seasonal environments or by possible difference in physiologic forms of rust.

Progenies of all 11 zero F_2 plants were similar in infection in F_3 to those of Hope and H-44, although only one was rust free. The average F_3 infection for each of the F_2 classes shows a somewhat more abundant infection in 1932 than in 1931. In general, the dominant inhibiting effect is similar under the more abundant infection, the mode shifting only from the 2% to the 10% class. The corrected F_2 distribution is similar to that of the Hope x Marquis and Hope x Reliance crosses studied in 1928[6] in that the total corrected F_2 distribution shows 28.4% of the strains nearly immune like H-44 and Hope. There also were 68.3% of the strains segregating or homozygous intermediate and 3.3% susceptible. This approximates the 4:11:1 phenotypic ratios reported in 1928 for these two crosses. None of the strains averaged quite so high as Marquis, although three actually averaged higher than any of the Ceres checks in amount of rust

The standard deviation of each of the F_3 strains and parent checks was determined. These data for the hybrids, in comparison with those for the parents, furnish a measurement for determining the homozygosity of the hybrid strains. Those strains showing the least variability and averaging as low as the parents in standard deviation are presumably homozygous. The data on standard deviation, together with the data on the average percentage of stem rust, are shown in Table 4. They show two distinct groups among the hybrids, i.e., 24 strains similar to H-44 in amount and variability of infection and 78 strains that cover a much wider range of infection and variability. Among this latter group are six strains that have as much or more rust than Ceres and no greater variability. Separated from the heterozygous group by a dotted line are eight additional strains that are no more variable for rust than Ceres but that have a slightly lower average infection. A study of the distribution, average infection, and standard deviation of the remaining strains shows that they may be grouped in four different segregating groups. The fact that there may be three kinds of true-breeding strains and four different segregating groups indicates that the inheritance is controlled by at least two genetic-factor pairs.

The rust inheritance of the H-44 x Ceres cross in 1932 appears similar to that reported in 1928 for the Hope x Marquis and Hope x Reliance crosses. Table 5 shows the data for the three crosses, which prove a good fit to the three phenotypic classes.

[6]See footnote 4.

TABLE 3.—*Average stem-rust infection of 102 F_3 strains of the H-44 x Ceres wheat cross in comparison with checks of the parents and of Hope and Marquis, with the original and corrected F_2 frequency distribution at Langdon, N. Dak., 1932.*

1932 average infection	Hope	H-44	F_2 stem-rust classes and F_3 strains grown							Ceres	Marquis	Corrected F_2	
			0	2	10	20	30	40	50			%	Total
0	1	1	1									0.2	
2	3	3	10	12	1							28.2	28.4
10				7	13	3	1					36.6	
20				2	4	5	1					14.1	
30					1	8	5					9.0	
40					2	4	7	2				8.6	68.3
50							5	3	1	3		2.3	
60								2		1		0.5	
70								2				0.5	
80											2		
90											2		3.3
Total	4	4	11	21	21	20	19	9	1	4	4		
Average	0.2*	0.1*	1.8	6.4	15.3	26.5	37.4	54.4	50.0	54.6*	84.4*		
Original F_2	0.7	1.2	2.6	42.5	31.8	15.1	5.7	2.1	0.2	30.3	46.9		100.0

*Actual average.

TABLE 4.—*Average stem-rust infection and standard deviation for 102 F_3 strains of the H-44 x Ceres wheat cross and parent checks at Langdon, N. Dak., 1932.*

Stem rust %	Standard deviation									Rust average %
	1	3	6	9	12	15	18	21	Average	
					H-44					
0	1									
2	3									
Total	4								1	0.1*
					Hybrids					
0	1								1	
2	22	1							1.1	
10			5	5	10	4			10.6	
20			2	1	2	4	2	1	13.5	
30			1	6	6	1			10.5	
40			5	9	1				8.2	
50			3	5	1				8.3	
60			1	1					7.5	
70			2						6.0	
Total	23	1	19	27	20	9	2	1	8.0	22.1
					Ceres					
50			3							
60			1							
Total			4						6.0	54.6*

*Actual average.

TABLE 5.—*Goodness of fit of the H-44 x Ceres, Hope x Marquis, and Hope x Reliance wheat crosses for stem-rust reaction in three phenotypic classes.*

	Phenotypic classes			Value of P
	Nearly immune	Segregating or resistant	Susceptible	
		H-44 x Ceres		
Obtained	29	70	3	
Calculated	26	70	6	
Deviations	3	0	3	0.40
		Hope x Marquis		
Obtained	31	96	5	
Calculated	33	91	8	
Deviations	2	5	3	0.48
		Hope x Reliance		
Obtained	21	56	3	
Calculated	20	55	5	
Deviations	1	1	2	0.66

GENETIC INTERPRETATION

A genetic interpretation for the 1928 results was suggested by assuming that a primary factor pair (II) was responsible for near immunity which reaction inhibits that of a second factor pair (SS) for susceptibility. Absence of the two dominant factors gives resistance.

The genotype for Hope (nearly immune) was postulated as IIss, that for Marquis and Reliance (susceptible) as iiSS, and that for Ceres (resistant) as iiss. In the present cross it may be postulated that the genotype for H-44 is IISS.

In both cases the phenotype, the genotypic group, and the breeding behavior in the F_3 generation, as indicated by the distribution of the plants of the F_3 strains, are shown as follows, with the modal reaction indicated by italics.

Phenotype	Genotypic group	Breeding behavior in the F_3 generation
Near-Immune		
1 IIss:		
2 IISs:	I	Nearly immune, breeding true
1 IISS:		
4		
Segregating and resistant		
2 Iiss	II	Segregating for *nearly immune* and resistant
4 IiSs	III	Segregating as F_2, *nearly immune*, resistant, and susceptible
2 IiSS	IV	Segregating for nearly immune, *resistant*, and susceptible
1 iiss	V	Resistant, breeding true
2 iiSs	VI	Segregating for resistant and *susceptible*
11		
Susceptible		
1 iiSS	VII	Susceptible, breeding true

This segregation is summarized in the following diagram in which the letters within the squares refer to the rust reactions:

	1 II	2 Ii	1 ii
1 ss	I Hope	*I*, R	R Ceres
2 Ss	I	*I*, R, S	R, *S*
1 SS	I H-44	I, *R*, S	S Marquis

Thus, there are seven different true-breeding or segregating genotypic groups.

In the H-44 x Ceres cross the segregating and true-breeding strains can be separated into these seven groups by using the F_3 data on distribution, average infection, and standard deviation. The data in Table 6 illustrate the types of segregation obtained by the low,

medium, and high variabilities allowed in each of the seven genotypic groups. Fig. 3 illustrates graphically one strain of the seven genotypic groups and one check row of Ceres and Marquis. Group I contains strains varying from 0 to 1.8% of rust. Most of the strains have a majority of the plants in the 0 class and the remainder in the 2% class. Group II contains strains averaging from 5.3 to 10.1% of rust with a majority of the plants in the 2% frequency. Group III is more variable and contains susceptible plants Its distribution is similar to that of the F_2. Group IV differs from Group III in having an intermediate rather than a dominant type of curve Groups V and VII are homozygous, including the strains that are no more variable than Ceres. They overlap in distribution and their average infections are not widely separated. Group VI differs from Group V and VII in being intermediate with strains having a larger standard deviation and are considered heterozygous. The Ceres checks average as near Group VII as Group V, although theoretically they should resemble the latter.

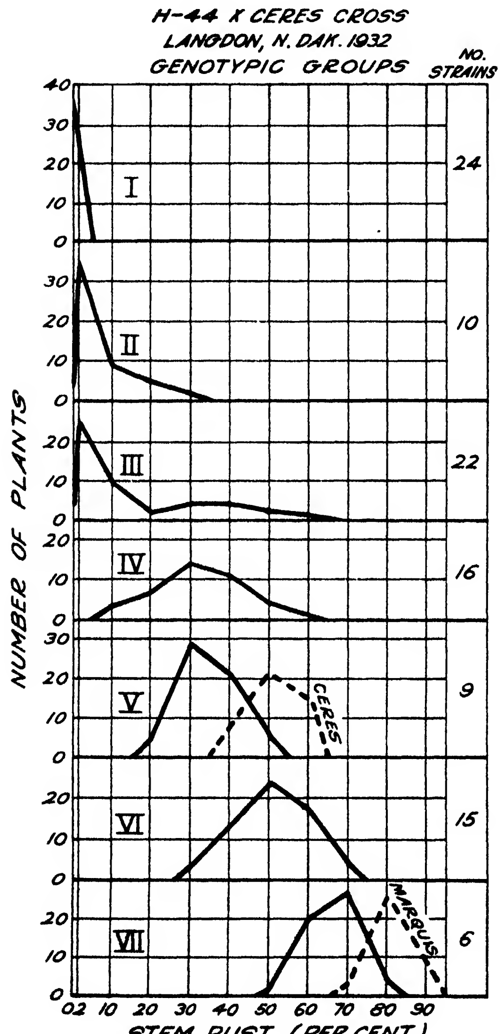

FIG. 3.—Frequency distribution of typical strains of the H-44 x Ceres cross representing seven genotypic groups at Langdon, N. Dak., 1932.

The 14 homozygous hybrid strains in Groups V and VII are to be grown again to determine more definitely which of the two varieties, Ceres or Marquis, they resemble, or whether they differ from either. From the present experiments the writers feel that Group V represents the Ceres genotype and Group VII the Marquis genotype. The greater infection of these varieties in comparison with that of the hybrids is thought to be due in part to their later

TABLE 6.—*Distribution of the plants for stem rust within each of seven genotypic groups, showing low, medium, and high infections, together with the average and standard deviation of selected strains.*

Genotypic groups	Row No.	F_2 rust	F_3 stem rust classes and plants in each strain										Average	Standard deviation
			0	2	10	20	30	40	50	60	70	80	Total		
I.	591	0	66										66	0.0	0.0
	609	2	36	26									62	0.8	1.0
	633	10	23	35	2								60	1.5	1.8
II.	564	2	19	15	11	5	1						51	5.3	7.2
	665	10	4	32	8	5	2						51	6.0	7.6
	573	20		29	21	3	9	1					63	10.1	10.3
III.	644	2	9	19	3	3	4	2					40	8.2	11.9
	597	10	4	25	9	2	4	4	2	1			51	12.2	15.9
	614	20		17	11	4	5	4	5	5			51	21.3	20.4
IV.	568	10		4	13	17	14	11	4				63	24.4	13.1
	669	20			3	7	14	12	4	1			41	32.4	11.4
	602	30			3	7	11	18	12	4			55	37.5	12.8
V.	631	10		1	12	24	13						50	19.8	7.5
	598	20				5	29	21	5				60	34.3	7.6
	588	30					17	34	8				59	38.5	6.4
VI.	652	20				8	9	14	13				44	37.3	10.7
	619	30					6	29	15	5	1		56	43.9	8.6
	657	40					4	14	24	18	4		64	50.6	10.0
VII.	641	40						14	27	16	1		58	50.7	7.6
	576	40							5	25	21	3	54	64.1	7.4
	675	40							2	20	27	4	53	66.2	6.8

maturity coupled with a more abundant inoculum. The H-44 parent is two to three days earlier than either Ceres or Marquis.

The 102 F_3 strains have been placed in these seven genotypic groups. The number of strains in each group is shown in Fig. 3 and in Table 7. The latter also shows the distribution of the plants in each percentage class. The different types of curves are further illustrated in Table 7 by the distribution of the total number of plants in each group.

TABLE 7.—*Genotypic groups, number of F_3 strains in each, and distribution of 5,652 F_3 plants of the H-44 x Ceres cross in each class and group at Langdon, N. Dak., 1932.*

Genotypic groups	F_3 strains No.	Stem-rust classes and number of F_3 plants										Average
		0	2	10	20	30	40	50	60	70	80	
I	24	793	522	11								0.9
II	10	54	280	135	52	31	8					7.5
III	22	98	722	233	118	112	100	41	11			11.3
IV	16		8	69	191	244	203	90	8			30.7
V	9		1	32	77	149	162	38	3			32.2
VI	15				31	119	259	243	85	20		43.9
VII	6					2	38	79	94	73	13	57.9
Total......	102	945	1,533	480	469	657	770	491	201	93	13	19.8

The goodness of fit for the three crosses H-44 x Ceres, Hope x Reliance, and Hope x. Marquis computed on the basis of seven genotypic groups is shown in Table 8. A very good fit is indicated for the H-44 x Ceres cross. The value of $P = 0.80$ indicates that 80 times out of 100 trials a poorer fit than the one obtained would be expected owing to chance alone. The fit also was good for the Hope x Reliance cross but poor for Hope x Marquis.

TABLE 8.—*Goodness of fit of H-44 x Ceres, Hope x Marquis, and Hope x Reliance wheat crosses for stem-rust reaction in seven genotypic groups.*

Genotypic group	H-44 x Ceres		Hope x Reliance		Hope x Marquis	
	Obtained	Calculated	Obtained	Calculated	Obtained	Calculated
I	24	25	17	20	30	33.0
II	10	13	14	10	19	16.5
III	22	25	26	20	53	33.0
IV	16	13	11	10	12	16.5
V	9	6.5	2	5	3	8.25
VI	15	13	6	10	9	16.5
VII	6	6.5	4	5	6	8.25
Total.....	102	102	80	80	132	132
Fit... ...	$\chi^2 = 3.09$	$P = 0.80$	$\chi^2 = 7.55$	$P = 0.28$	$\chi^2 = 21.36$	$P = 0.002$

DISCUSSION

A similar inheritance for the H-44 x Ceres cross (IISS x iiss) with that of the Hope x Marquis and Hope x Reliance crosses (IIss x iiSS) is indicated, proving a two-factor inheritance with one dominant

inhibiting factor for near immunity and one major dominant factor for susceptibility with the resistant reaction recessive.

These findings agree with those of Goulden, *et al.* (2) in that the H-44 x Marquis cross differs by one factor, and with the findings of Neatby and Goulden (3) in that the Hope x Marquis cross differs by two factors.

The crosses of Hope and H-44 with the more susceptible varieties Supreme, Power, and Reward suggest the presence of more than one factor for susceptibility. The additional factor or factors apparently are of minor importance. Their presence, however, tends to lessen the effect of the dominant inhibiting factor for near immunity and to shift the F_2 segregation towards a more nearly normal curve.

On the other hand, there is only slight suggestion of more than one dominant factor for near-immunity, as the single-factor segregation for this reaction is most striking. If additional factors are present they must be considered in the category of modifying factors. The data for the Hope x Ceres cross in 1928 under light infection and those for the H-44 x Ceres cross in 1932 under heavy infection do show, however, a tendency toward piling up near the zero end of the distribution which can not be completely explained on the basis of a single-factor difference. In the latter cross only one of the 24 near-immune F_3 strains was entirely rust free. Further research to show if this one strain is inherently different from the 23 strains averaging from 0.1 to 1.8% of rust should furnish additional information as to the presence of modifying factors. If modifying factors are present the problem of the breeder is to combine in a single variety as many factors as are necessary to insure the continuation of immunity from rust under any environment.

SUMMARY

The inheritance of the three stem-rust reactions, i.e., near immunity, resistance, and susceptibility, has been studied in hybrids. Earlier data on crosses of Hope x Marquis and Hope x Reliance were interpreted to show that they were controlled by two genetic factor pairs. Data on an H-44 x Ceres cross showed a segregation similar to that previously obtained in the crosses of Hope x Marquis and Hope x Reliance. These results are interpreted as showing that Hope has a single dominant inhibiting factor for near-immunity, that Marquis and Reliance have a dominant factor of susceptibility, that H-44 carries both of these dominant factors, and that the resistant Ceres carries the double recessives.

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INOCULATION OF LEGUMES AS RELATED TO SOIL ACIDITY[1]

Wm. A. Albrecht[2]

The significance of soil acidity as a factor influencing legume growth and inoculation has long been recognized. Reaction, or degree of acidity, as it influences the behavior of the legume bacteria both within the plant and outside of it on special media has been widely studied. Ranges in reaction tolerated by the plants (8, 9, 14)[3] and similarly for their particular variety of bacteria have been specified (8, 12). Inconsistencies in these reaction ranges (8, 9, 10, 15) with differing other factors in the experimental conditions have pointed to the need for further study of the influence of soil acidity as a factor affecting legume inoculation.

PHASES OF THE PROBLEM

Effective inoculation, or the entrance of the legume bacteria into the host plant and their function in nodule production and nitrogen fixation there, requires, first, the presence of the specific viable bacteria, and second, the healthy growing plant which is susceptible to the entrance of bacteria and able to bring about development of nodules with nitrogen fixation within them. If soil acidity exercises detrimental effects, it may do so by its effects on the bacteria, on the plant, or on both. It may either destroy the bacteria or lessen their ability to effect entrance. It may bring about a non-susceptibility of the plant, or it may do both.

Soil acidity may be considered as representing roughly (a) an environmental condition in which the excessive hydrogen-ion concentration is intolerable and (b) an irregularity in nutrition of either or both the bacteria and the plant, possibly through shortage of basic elements replaced by the hydrogen, or through injury to, or disturbance of, the plant's mechanisms for absorption and utilization of the necessary nutrient elements. Since soil acidity represents a loss of basic elements while the content of hydrogen increases, the question naturally arises whether the injurious effect of acidity to inoculation may not be due to an irregularity in the plant's supply of bases as well as to the presence of the excessive hydrogen-ion concentration. The following work was undertaken in an attempt to separate and measure, in part, the effects of these two phases of soil acidity on legume inoculation.

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo., Journal Series No. 356. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication November 18, 1932.

[2]Professor of Soils. The author expresses his appreciation to Wilbur R. Bryant, graduate assistant in soils, for his help in much of the work reported herein.

[3]Numbers in parenthesis refer to "Literature Cited," page 522.

PREVIOUS WORK

As the supply of bases in the soil naturally decreases with the development of soil acidity, calcium is the one base more readily removed, hence it presents itself as a possibly deficient element (15, 16). The importance of calcium over many other bases in connection with inoculation has been pointed out (2, 6). Its influences on this process without apparent change of, or influence upon, the soil's reaction (4, 5, 6) have served to direct thought to its importance as a nutrient element in the inoculation process as related to soil acidity. That this importance manifests itself not so much through the bacteria as through the plant (3) is indicated by the observation that ineffective inoculation or complete inoculation failure on acid soils have resulted when bacteria were plentifully present as revealed by their successful inoculation of the following crop through the simple addition of different forms of calcium salts to the soil. Moderately good inoculation on acid soil has been improved decidedly by calcium addition only (3). Also, the growth of the soybean plants for but 10 days in a liberal supply of calcium increased their growth, nodule production, and nitrogen fixation over those grown similarly on a deficient calcium supply, when both kinds of plants were transplanted to an inoculated acid soil (1). It has also been shown in studies with a variable supply of calcium under constant degrees of acidity (2) that larger amounts of calcium were needed to bring about inoculation of soybeans than were necessary for apparently normal growth.

These observations of the significance of calcium in connection with inoculation prompted the following attempt to study the effects of different levels of calcium through a wide range of different degrees of acidity on the inoculation of soybeans.

METHODS USED

The soybean plant was selected in consequence of previous studies of it under tests with a controlled supply of calcium and controlled reaction (6) which revealed the behavior of this plant over a range in its calcium supply and at different degrees of reaction. Limits in these respects for this plant under familiar experimental conditions were thus already established. The control of the pH, and of the supply of calcium, was possible through recourse to colloidal clay as previously used (2, 6).

The electrodialyzed clay (7), with an initial pH of 3.35, was titrated with calcium hydroxide to produce Ca-H clays of the degrees of acidity desired, according to the titration curve in Fig 1. These clays of different degrees of acidity were then taken in such amounts as needed to supply the desired amount of calcium per plant and mixed into constant amounts of quartz sand for growing 50 plants. Three different amounts, or levels, of calcium, *viz.*, 0.05,

0.10, and 0.20 M.E.,[4] were provided through a pH range from 4.0 to 6.5 by intervals of 0.5 pH. These amounts of calcium represented low, medium, and high levels as indicated by previous trials

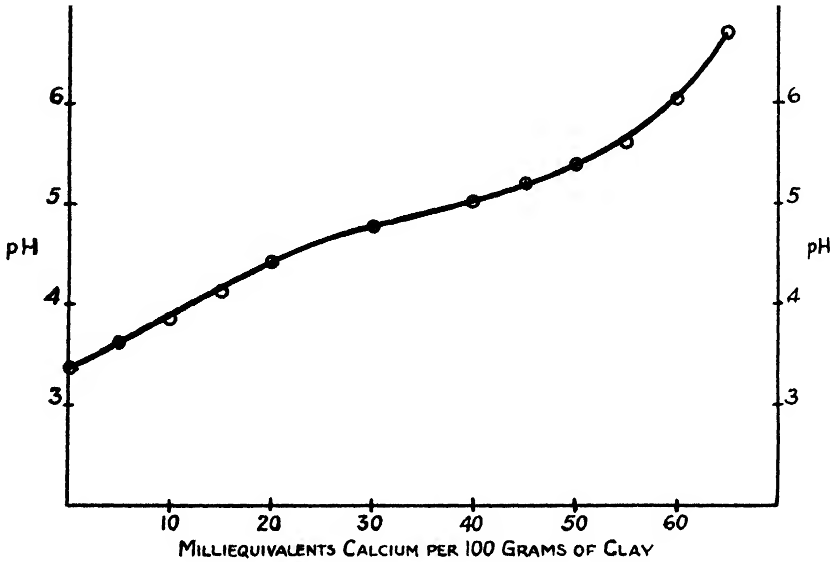

FIG. 1.—Titration curve of hydrogen clay and calcium hydroxide.

(2). These standardized sand-clay media were each planted with 50 soybeans which had been sterilized, soaked in distilled water, and germinated between filter papers until the radicles were about 1 cm long. The moisture content was maintained at optimum by controlled weights of distilled water added daily. The growth period was 4 weeks.

EXPERIMENTAL RESULTS

GROWTH DIFFERENCES, FIRST SERIES

Differences in growth were noticeable early and persisted through the period of observation. Brown spots along the lighter green edges were a symptom that seemed to increase with lesser calcium and greater degree of acidity. The height and weight of plants were related to both the degree of acidity and the amount of calcium, as shown in Fig. 2. None of the plants died, but with the highest degree of acidity at all three levels of calcium they failed to grow much beyond the production of the first pair of small leaves just above the cotyledon. Growth improved with decreasing acidity, so that at nearly neutral reaction and even with the lowest amount of calcium the growth was very good. This points out that the sensitivity of the plants to soil reaction is greater as the

[4]Milliequivalents.

calcium supply is less, in accordance with the observation Mitscherlich (13) reports for acidity and the nutrient supply.

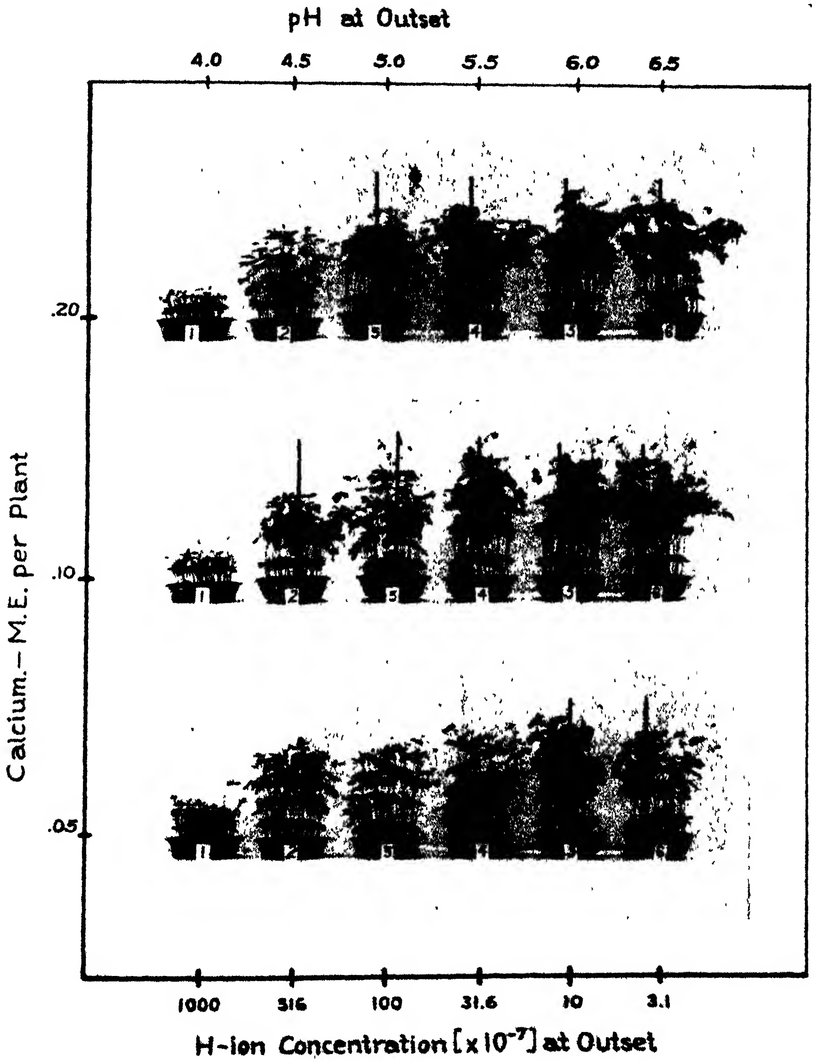

FIG. 2.—Soybean growth according to varying degrees of acidity at different calcium levels.

The influence of the varying amounts of calcium on the growth was decidedly significant. This was without influence at pH 4.0 and 4.5 which gave very poor growth, but of decided influence at all pH figures tested above these. The effects of the degree of reaction were displaced or offset by increasing amounts of calcium.

This is clearly evident from Table 1. The 0.20 M.E. calcium at pH 5.5 produced the equivalent in height of and were superior in weight to that with 0.10 M.E. calcium at pH 6.5. An increase of 10 times in acidity was offset in its effects on growth by merely doubling the amount of calcium. Many other comparisons within this table point to similar differences, suggesting calcium from 2½ to 5 times as significant in growth as is the degree of acidity within the ranges tested.

TABLE 1.—*Nodulation and growth of soybeans (first crop) as influenced by the calcium and by the pH of calcium-clay soils.*

Plant characters		Calcium per plant, M.E.*	pH at outset (first crop)					
			4.0	4.5	5.0	5.5	6.0	6.5
Nodules, 50 plants		0.05	0	0	0	0	7	14
		0.10	0	0	0	8	28	40
		0.20	0	0	0	60	69	127
Height, cm		0.05	11	26	28	31	36	36
		0.10	9.5	27	34	42	44	45
		0.20	8	25	40	45	48	52
Weight of 50 plants in grams	Tops	0.05	4.8	6.3	6.8	7.0	7.9	7.6
		0.10	4.2	6.3	7.3	8.9	9.5	8.7
		0.20	4.6	6.0	8.7	9.2	9.4	9.9
	Roots	0.05	1.5	2.5	2.0	2.0	4.0	3.6
		0.10	1.7	2.2	2.1	4.3	4.3	4.2
		0.20	1.0	1.7	2.5			

*Milliequivalents per plant.

DIFFERENCES IN NODULE PRODUCTION, FIRST SERIES

The production of nodules points out clearly that, as in the case of growth, both the degree of reaction and the amount of calcium are significant. Though all plants were similarly treated with bacteria at the outset, no nodules were produced by the soybean plants at pH 5 or greater acidities, suggesting a possible critical limit in acidity beyond which no nodule production may be expected. Above this pH figure nodule numbers increased with lessening acidity at constant calcium levels. Far more significant, however, was the increase in nodule numbers at constant pH levels with the increasing amount of calcium. The variation in calcium may even cause a decided shift in the suggested initial acidity limit. According to Table 1 this limit falls between pH 6.0 and 5.5 when 0.05 M.E. of calcium are present, but falls between pH 5.5 and 5.0

when 0.10 or 0.20 M.E. of calcium are present. Irregularities in past attempts to specify or to duplicate pH limits for inoculation may have been due to variations in the calcium supply.

With reference to the number of nodules produced, the effect of calcium is far more outstanding than that of acidity. An examination of the table reveals that merely doubling the amount of calcium at a constant pH figure approximately doubled the nodule numbers, while at a constant calcium level a corresponding improvement occurred with a 0.5 pH increase, or a reduction in degree of acidity by one-third. This suggests that, in general, calcium is about 1.5 times as influential on nodule numbers as is the hydrogen-ion concentration.

With 0.1 M.E. of calcium per plant present, the nodule numbers per unit calcium increased 100% in going from pH 5.5 to 6.0 and about 70% in going from pH 6.0 to 6.5. With 0.2 M.E. of calcium per plant present, these corresponding pH changes represented roughly 3% and 25% increases, respectively, or a lesser variation due to the pH change as the amount of calcium was increased. These variations occurred in consequence of changing the acidity by one-third at constant amounts of calcium. By using constant pH figures while the calcium was varied, doubling the latter at pH 5.5 meant an increase of 600% in nodule numbers per unit calcium; doubling it at pH 6.0 meant 300% increase; and at pH 6.5, this same rise in calcium amount increased by 200% the nodules per unit of calcium. This points out clearly the greater influence of the calcium in contrast to that of the hydrogen-ion concentration on the nodulation of the soybeans within these higher pH figures and the conditions of the experiment.

SOIL REACTION CHANGES IN CONSEQUENCE OF CROP GROWTH

After the crop was removed, electrometric determinations of the pH of the soil were made. Some of the original clays as made up, titrated at the outset and stored without mixing into the sand, were also tested for their pH. They showed no significant changes from their original record. Mixing these into the sand caused no change in degree of reaction. Hence changes of pH in the sand-clay mixtures growing the plants could not be innate to the clays nor due to the mixing of them with the sand. Their changes in this respect must be ascribed to the activities of the growing plants.

It is interesting to note the changes in the pH of these different soils as given in Fig. 3. The more acid soils, those below pH 5.5 became less acid, while those less acid, above this figure, changed to a more acid condition. These changes were greater as the original pH figures were further above or below 5.5. The changes were greater above 5.5 with the extreme one in the most nearly neutral soil. By using the calcium analyses of the seeds and clay at the outset and of the final plants as a means of calculating the calcium left in the clay, and thus its corresponding pH (Fig. 1)

at the close of the growth of this series, the pH figure for the clay by determination was higher or the clay was less acid than by the calculations based on the assumption of calcium removal and its substitution by hydrogen. This was true for all of the 18 trials

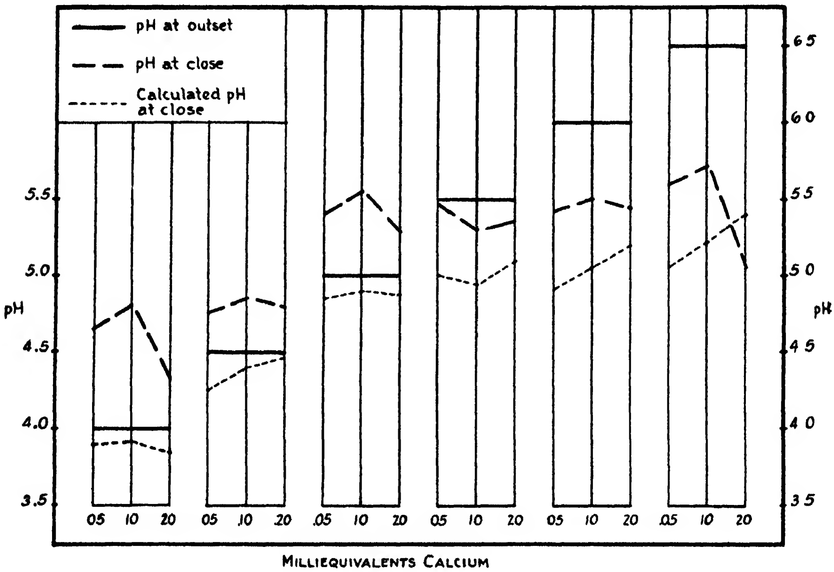

Fig. 3.—Changes in pH of calcium clay soils in consequence of soybean growth (first series).

except for the one at pH 6.5 with 0.20 M.E. of calcium. The difference between the actual and calculated figures was relatively constant, ranging from 0.2 to 0.8 pH, or an average of almost 0.5 pH. As for the cause of these differences, theoretical discussion must be omitted here and further work is necessary to establish such.

GROWTH DIFFERENCES, SECOND SERIES

Following the growth of the first series and the complete removal of the crop, another crop was planted without any change of the soil or procedure. Soon after the plants were started many of them showed irregularities in growth and symptoms of calcium shortage which might be mistaken for "damping-off", as previously described (5). The number of plants so affected was, in general, inversely related to the amount of calcium in the substrate at any one constant pH figure and to the changes in this figure. Many plants were thus eliminated due to calcium shortage, showing the influence of the calcium depletion by the first crop upon the second. After 3 weeks, the crop growth was widely different in appearance and in weights according to the calcium supply and pH of the soil as given in Fig. 4.

Growth was very poor on all the pans, but it was decidedly better on those same pans where the best growth had occurred previously. Again the growth differences were related more pronouncedly to the calcium than to the pH. Due to the changes in

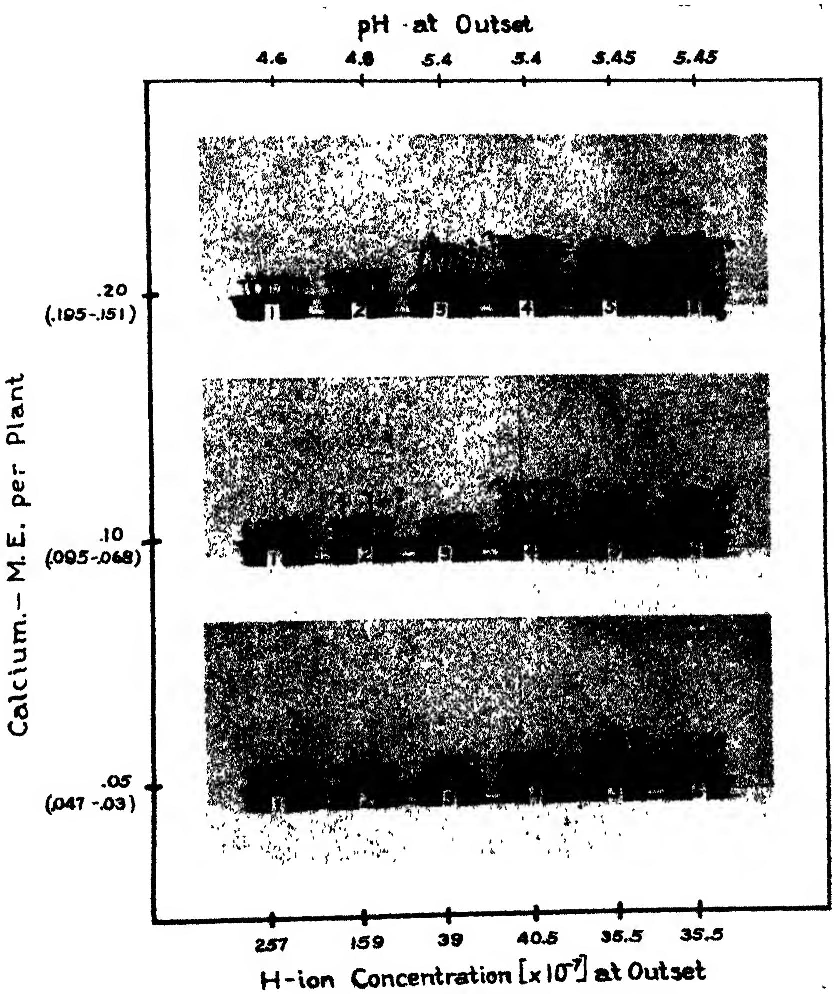

FIG. 4.—Soybean growth of second crop according to varying degrees of acidity at different calcium levels.

the reaction brought about by the previous crop, 4 pans in each series, or 12 pans in all were of nearly equal acidity, pH 5.4. Even though their reaction was nearly uniform, yet at the low calcium level two of these four gave better growth; at the medium calcium level, three of the four grew better; and at the higher calcium

level all four pans had the better growth. These differences are shown by the figures for height in Table 2. Such a disparity in growth at almost constant pH certainly suggests little control over the growth by the pH and points forcibly to the importance of the calcium in bringing about these growth differences at this rather acid figure of pH 5.4.

TABLE 2.—*Nodulation and growth of soybeans (second crop) as influenced by the calcium and by the pH of calcium-clay soils.*

Plant characters	Calcium per plant, M.E.*	pH at outset (second crop)					
		4.6	4.8	5.4	5.4	5.45	5.45
Nodules, per pan	0.05†	0	0	0	0	4	0
	0.10	0	0	0	0	4	6
	0.20	0	0	0	0	0	3
Dead plants	0.05	14	16	6	9	3	16
	0.10	20	8	1	1	2	1
	0.20	35	14	1	1	0	0
Average height, cm	0.05	6.0	9.0	7.5	7.5	18.5	17.0
	0.10	7.5	10.0	7.5	20.5	21.0	20.0
	0.20	5.0	10.5	20.5	22.0	21.0	22 0
Weight per plant, grams	0.05	0.0767	0.0880	0.0740	0.0820	0.0946	0.1058
	0.10	0.0792	0.0772	0.0752	0.0754	0.0896	0.0996
	0.20	0.0596	0.0819	0.0993	0.1055	0.1074	0.1233

*Milliequivalents per plant.

†The calcium supply was reduced by the first crop to a range of 0.047–0.03 in the 0.05 series, to 0.095–0.068 in the 0.10 series, and to 0.195–0.151 in the 0.20 series.

NODULATION OF THE SECOND SERIES

Although many nodules had been produced by the previous crop and although the 18 pans were reinoculated at the second planting, nodules developed in only 4 of them. Nodules were formed on less than a dozen plants. The failure of nodulation on plants of medium or poor growth in the first series suggests that nodulation could scarcely be expected in this second series when the growth was so much poorer. The growth period of only 3 weeks may have been too short for nodules to develop. The growth of the second crop was so much inferior to that of the first and nodulated crop at the same age, however, that the low calcium supply suggests itself as the responsible factor rather than the age of the plants.

REACTION CHANGES IN CONSEQUENCE OF SECOND CROP

Since the growth of the first crop brought about significant changes in the acidity of the soil, determinations of the pH of the soil were made at the close of the second crop. These determinations, together with those at the close of the first series and at the outset, are brought together in Fig. 5.

It is interesting to note that the second crop brought additional changes in reaction in the same direction as was true for the first

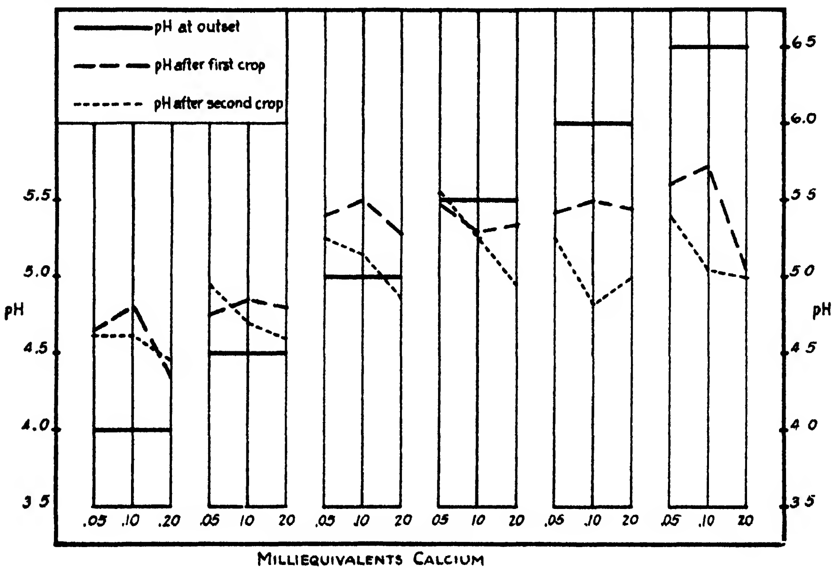

Fig 5.—Changes in the pH of calcium clay soils in consequence of growth of two crops of soybeans.

crop. Further, these changes in reaction tended to make the degree of reaction more nearly the same for all the pans. This leveling effect on the degree of acidity after the second crop was greatest with the largest calcium supply and the greater pH. The three series of six pans each whose initial pH figures ranged from 4.00 to 6.50 were reduced by the two crops to the narrow pH range of 4.46 to 5.00. This suggests a figure of pH 5.00, or slightly below it, as the probable acidity limit of the soil under test below which only a poor activity of the young crop of soybeans will be possible.

SUMMARY

As a result of these studies on nodule production by soybeans as correlated with the degree of acidity and the available calcium supply in the soil, it is evident that the degree of soil acidity is responsible as an environmental factor for nodulation failure on excessively sour soils. In the experiments reported herewith, the acidity at which this failure occurred was at pH 5.0 and lower

values. With pH figures larger than this, or soils less acid, the nodulation failure was brought about not so much by the degree of acidity as by the deficiency of the available calcium in the soil. These data point to a decided effect of the element calcium on nodule production in soils with a pH of 5.5 and higher and to an increasing nutritional influence of this element as the soils are less acid. These experiments separate for the first time the effect on nodulation of hydrogen-ion concentration from that of available calcium and further serve to direct attention to the supply of available calcium of the soil as one of the essential conditions for growth and thorough inoculation of soybeans, or possibly other legume crops. They indicate a significance of calcium in symbiotic nitrogen fixation as has been shown for it in the non-symbiotic process (11). They emphasize need for consideration of fertilizing with calcium on the less sour soils as well as changing the reaction in those of higher degree of acidity, if soybeans and possibly other legume crops are to grow well and to be thoroughly inoculated.

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CORRECTION OF THE UNPRODUCTIVITY OF A PEAT SOIL FOR LETTUCE[1]

B. D. Wilson and G. R. Townsend[2]

Peat soils vary in productivity with respect to vegetable crops. Often lettuce and spinach cannot be grown successfully on certain peat soils that will produce marketable crops of potatoes. Relationships of this kind have been observed by Felix (2)[3] for peat soils of New York and by Allison, Bryan, and Hunter (1) for peat soils of Florida. Such areas vary considerably in size. They may comprise large tracts of soil or they may be only a few feet in diameter. In many cases normal plants are found growing adjacent to abnormal plants.

The present paper is concerned with the correction of the unproductivity of a peat soil of this character for lettuce

INDICATIONS OF UNPRODUCTIVITY

Several unsuccessful attempts had been made in the field to produce marketable crops of lettuce on the soil of the investigation. Lettuce seed germinated normally, but the young plants became extremely chlorotic 2 or 3 weeks after germination. This condition was accompanied by the appearance of necrotic spots at the tips and on the margins of the leaves which finally curled and died. Because no organism could be isolated from the leaves or the roots of the plants to account for the symptoms that are described, it appeared that the cause of the abnormalities was nutritional.

THE SOIL OF THE INVESTIGATION

The soil of the investigation is composed of well-decomposed woody-reed peat to a depth of 10 inches. Below that level the soil is characterized by fibrous-reedy peat, yellowish-brown in color. The deposit, which is approximately 4 feet deep, is underlain with grayish-blue clay that is non-calcareous.[4] The soil was sampled to a depth of about 10 inches in several places where lettuce had failed to grow.

At the time the soil was collected for study its reaction was pH 4.8 and it contained 2.10% of calcium expressed as calcium oxide. These values are lower than are those for most of the peat soils of New York.

[1]Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication November 30, 1932.

[2]Assistant Professor of Soil Technology, Cornell University, and Associate Plant Pathologist, Everglades Experiment Station, Bell Glade, Florida, respectively.

[3]Reference by number is to "Literature Cited," page 527.

[4]The writers are indebted to Dr. A. P. Dachnowski-Stokes of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, for a detailed description of the profile of this soil. Only a partial description is given in the present paper.

EXPERIMENTAL

The soil was brought to the laboratory, thoroughly mixed, and used in greenhouse experiments. Indoor tests seemed advisable because of the difficulties that are sometimes encountered with field experiments on peat soils owing to occasional floods and windstorms. Glazed earthenware pots of 1-gallon capacity were filled with the soil which was held throughout the investigation at a moisture content of 160.0% of dry soil.

Field observations and tests for soil reaction had shown that soils more acid than pH 5.0 were usually unproductive for lettuce. In the light of this experience, a preliminary experiment was conducted in which the soil of some of the pots was limed. Treating the soil with c. p. precipitated $CaCO_3$ at the rate of 2,400 pounds to the acre which changed the reaction of the soil from pH 4.8 to pH 5.7 prevented, in large measure, the chlorotic condition of the plants and the attendant symptoms of unproductivity. But damping-off occurred to such an extent that few normal plants were present on the soil 3 weeks after the seed was sown. Damping-off was caused by a fungus (*Pythium* sp.), which was isolated from the seedlings.

Subsequent experiments with the potted soils showed that damping-off of the plants could be controlled partially by dusting the seed with CuO or by applying $CuSO_4$ to the soil. These treatments were used because Horsfall (3) had found that the damping-off of tomato seedlings could be controlled by dusting the seed with copper salts. The data recorded in Table 1 were obtained by the writers from an experiment in which natural or copper-treated seed was sown in natural and in limed soil. The test consisted of 32 pots of soil, 16 of which were limed at the rate of 2,400 pounds of $CaCO_3$ to the acre. Eight of the potted soils in both the limed and the unlimed series were planted, respectively, with seed that was dusted with CuO or with seed that was not treated. The figures of the table are based on the total number of plants that grew on all of the soils of the same treatment. The variety of lettuce grown was Big Boston.

TABLE 1.—*The effect of lime and copper on correcting the unproductivity of a pea soil for lettuce.*

Soil and seed treatment	Plants germinating		Plants damping-off		Abnormal plants		Normal plants	
	No.	%	No.	%*	No.	%*	No.	%*
No treatment	375	27	161	43	134	36	80	21
$CaCO_3$ in soil	259	19	105	41	19	7	135	52
CuO on seed	821	59	273	33	201	25	347	42
$CaCO_3$ in soil and CUO on seed	871	62	272	31	74	9	525	60

*Percentage of plants which germinated.

It may be seen from the table that dusting the seed with CuO increased germination and decreased both the percentage of damping-off and the percentage of abnormal plants. Lime is shown also to have decreased the percentage of abnormal plants, but its effect

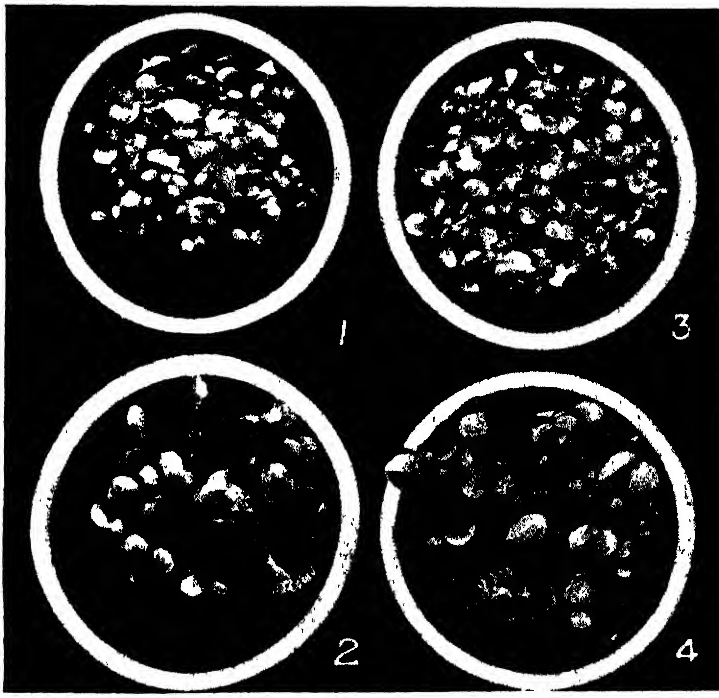

FIG. 1.—1, no treatment; 2, soil treated with lime; 3, seed treated with copper; and 4, soil treated with lime and seed treated with copper.

was much more pronounced than was that of copper. The largest number of normal plants were obtained from copper-treated seed that was sown in limed soil. In that case 60% of the seed that germinated produced healthy plants. This value may appear small, but the soil of these pots was well covered with plants. This fact is shown effectively in Fig. 1. The pots of the figure are representative of the type and the extent of growth that was effected by the respective soil treatments.

The seedlings that did not damp-off on the limed soil developed into healthy green plants. Dusting the seed with CuO reduced the damping-off of the seedlings, but most of the plants exhibited symptoms of unproductivity. Treating the soil with lime and the seed with CuO resulted in a good stand of normal plants. Those that grew on the soils receiving no treatment were dead at the end of 3 weeks.

The appearance of the leaves of normal and abnormal plants is shown in Fig. 2. The leaves of the abnormal plants were chlorotic and stunted. Necrotic lesions were present on the margins of the leaves which turned brown and died.

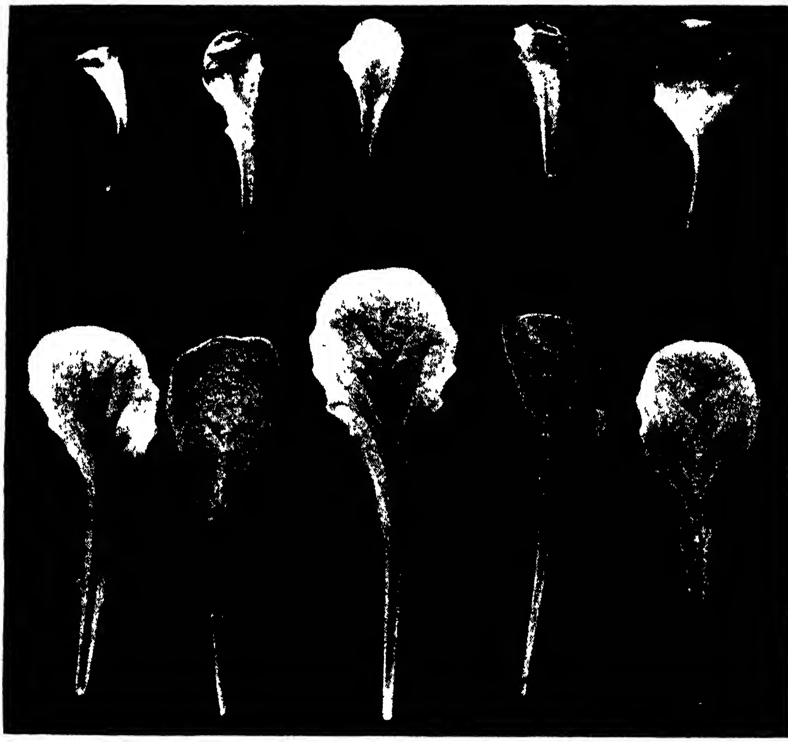

FIG. 2.—Top rows, leaves of abnormal lettuce plants; bottom row, leaves of normal lettuce plants.

Copper sulfate applied to the potted soils at the rate of 50 pounds to the acre was not as effective in controlling the damping-off of the plants as was the dusting of the seed with CuO. However, it is probable that larger applications of $CuSO_4$ to the soil would have proved more efficient.

FIELD TREATMENTS

That plants will often respond favorably to treatments of copper with respect to both mineral and organic soils has been shown by a number of investigators. The experiments of Hudig and Meyer (4), Felix (2), and Allison, Bryan, and Hunter (1) are among those that have shown the value of adding copper to peat soil in order to improve the growth and the quality of different kinds of plants. Felix (2) observed that copper would prevent

or correct an abnormality in the growth of lettuce called *rabbit ear*. The treatment was effective whether the copper was applied directly to the plants or to the peat soils with which he worked.

The soil of the present investigation, when treated in the field at the rate of 3,000 pounds of hydrated lime and 200 pounds of $CuSO_4$ to the acre, produced large crops of marketable lettuce. Because the damping-off of lettuce seedlings under field conditions is not a serious problem on New York peat soils, it is probable that lime was the principal agent in correcting the unproductivity of the soil for lettuce. Nevertheless, it would seem in the light of the greenhouse experiments here reviewed, that the copper was a contributing factor in making the soil more productive. Experiments now in progress may throw additional light on this question.

Although an application of lime to the soil of the investigation made it more productive for lettuce, the addition of lime to most of the cultivated peat soils of New York is not to be recommended.

SUMMARY

A peat soil that was unproductive for lettuce was made more productive for the growth of the plant by treating the soil with lime and the seed with CuO.

The action of the lime was to correct a soil condition that caused the plants to become chlorotic, the leaves to curl, the appearance of necrotic spots at the tips and on the margins of the leaves, and the death of the plants in the early stages of growth.

The action of the copper was to increase the germination of the seed, to decrease considerably the damping-off of the seedlings, and to decrease to some extent the development of abnormal plants. Copper sulfate added to the soil was not as effective in this regard as was dusting the seed with CuO.

Treating the soil in the field with lime and with $CuSO_4$ resulted in the production of normal crops of marketable lettuce.

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WINTERHARDINESS IN THE FIRST GENERATION OF SEVERAL WHEAT CROSSES[1]

C. E. ROSENQUIST[2]

Very few results have been published which show the behavior of F_1 hybrid wheat plants with respect to cold endurance in comparison with their parents under conditions causing severe winter killing. Some results obtained in the winter of 1927–28 comparing 522 hybrid plants with 1,055 parent plants in respect to winterhardiness may be of interest. The plants reported upon were grown for the purpose of studying hybrid vigor, but they also afforded a good opportunity to observe the inheritance of winterhardiness in the F_1 generation, since the winter was unusually severe and much winter killing obtained in the winter wheat nursery of the Nebraska Experiment Station at Lincoln, Nebr., where the plants were grown.

Enough data have been amassed by several investigators (1, 2, 3, 4, 5, 6, and 9)[3] to indicate that the character winterhardiness is complicated in its inheritance and is probably dependent upon the reaction of several genes.

Åkerman (1), studying two different crosses of common wheat, found most of the lines resulting from these crosses to be intermediate in winterhardiness, though there were lines within the range of either parent. Martin (3), obtained practically the same results as did Åkerman when using bulked progenies of 36 different crosses. Some lines less hardy and some more hardy than either parent of a cross between two lines of intermediate hardiness were obtained by Nilsson-Ehle (4). He concluded that winterhardiness was controlled by many genetic factors.

Using F_3, F_4, and F_5 generations of several winter wheat crosses, Quisenberry and Clark (5) found that "in most cases, hybrids showed a survival intermediate to that of the parents. There are, however, exceptions; in some instances the hybrids ranked higher than either parent . . . In some instances the hybrids were less hardy than either parent." Schafer (9) reported the inheritance of winterhardiness in a cross between Turkey and Jenkin to react as a recessive character.

Quisenberry (5), using mostly F_2 and F_3 of a winter by spring wheat cross, found that the "winterhardiness character appears to be controlled by several genetic factors, the final expression being greatly influenced by the environment under which the material is grown." In every case where the F_1 was tested under severe conditions all plants were killed. Since quite a complete review of the literature was given, anyone further interested should refer to this article.

[1]Contribution from the Department of Botany, University of Nebraska, Lincoln, Nebr. Received for publication December 3, 1932.

[2]Assistant Professor.

[3]Reference by number is to "Literature Cited," page 533.

METHODS

The methods used in producing the crossed kernels and carrying on the experiment have been explained in former articles (7 and 8), but some further explanations may be necessary. The parents and F_1 hybrid plants were grown in alternate rows, which were 10 inches apart, and the seeds were spaced 4 inches apart in the row. During the unfavorable winter of 1927–28 many less hardy varieties were completely killed out while nearly all varieties grown in the wheat nursery were injured. An initial plant count was taken in the late fall of the plants which established themselves and another in the spring of those plants which finally survived the winter.

RESULTS

Fifteen varieties, some of which were hardy, some intermediate, and some non-hardy, were used in the test. Table 1 shows the results obtained from 21 different crosses between these varieties. No plants of four varieties and only 5% or less of the plants of four other varieties survived the winter. About 50% of five varieties and 25% of two other varieties, however, were able to survive. This gives an indication of the severity of the winter of 1927–28, as well as of the variation in winterhardiness among the parent varieties.

The F_1 hybrids as a whole approached the hardiness of the more hardy parent. Three of the hybrids, or 14%, were similar to the less hardy parent, while six, or 29%, were intermediate and 12, or 57%, resembled the more hardy parent in cold resistance. Of the 12 hybrids which were similar to the more hardy parent in winterhardiness, 3 were about the same as the hardy parent, while 9 were even more hardy. The results from these 12 hybrids suggest complete dominance, while those of 6 of the remaining 9 hybrids suggest partial dominance.

A summary comparing the survival percentage and relative survival, when using the average of the F_1 hybrids as 100, is presented in Table 2. About 34% of the F_1 hybrid plants survived the winter, while only 19.9% of the variety plants were able to survive. The average survival of the hardy parents occurring in each cross was 37.4% and that of the less hardy parents 7.1%. The four hardiest parent varieties showed a survival of 49.8%, while no plants whatever of the four least hardy parents came through the winter.

The relative survivals when using the F_1 hybrids as 100 were 100, 59, 110, 21, 147, and 0, respectively, for the F_1 hybrids, parent varieties, hardier parents, less hardy parents, four hardiest parents, and four least hardy parents. This shows the F_1 hybrids to be nearly twice as hardy as the average of the parents and about five times as hardy as the less hardy parents. They were, however, slightly less hardy than the average of the hardier parents and

TABLE 1.—*Winterhardiness of varieties and F_1 hybrids of winter wheat in 1927–28.*

Varieties and hybrids	Number of plants in fall	Number of plants maturing	Survival %
611 Minturki	87	66	75.9
611 x 615	65	28	43.1
615 Michigan Amber	95	2	2.1
614 Minnesota Reliable	70	16	22.9
614 x 615	62	11	17.7
615 Michigan Amber	51	2	3.9
613 Hardy Northern	21	10	47.6
613 x 615	10	2	20.0
615 Michigan Amber	51	2	3.9
751 Nebraska 28 bearded	12	0	0.0
751 x 615	12	1	8.3
615 Michigan Amber	51	2	3.9
611 Minturki	66	39	59.1
611 x 613	19	13	68.4
613 Hardy Northern	21	10	47.6
611 Minturki	66	39	59.1
611 x 612	21	3	14.3
612 Fulhio	43	0	0.0
752 Nebraska 28 beardless	14	0	0.0
752 x 611	12	9	75.0
611 Minturki	66	39	59.1
612 Fulhio	43	0	0.0
612 x 613	8	0	0.0
613 Hardy Northern	38	15	39.5
614 Minnesota Reliable	29	6	20.7
614 x 612	11	0	0.0
612 Fulhio	43	0	0.0
752 Nebraska 28 beardless	55	1	1.8
752 x 614	35	8	22.9
614 Minnesota Reliable	29	6	20.7
751 Nebraska 28 bearded	30	0	0.0
751 x 31	35	3	8.6
31 Red Cross	87	2	2.3
751 Nebraska 28 bearded	30	0	0.0
751 x 742	42	1	2.4
742 Dawson's Golden Chaff	41	0	0.0
31 Red Cross	87	2	2.3
31 x 742	8	0	0.0
742 Dawson's Golden Chaff	41	0	0.0
31 Red Cross	87	2	2.3
31 x 2	4	3	75.0
2 Indiana Swamp	29	4	13.8

TABLE 1.—*Concluded.*

Varieties and hybrids	Number of plants in fall	Number of plants maturing	Survival %
2 Indiana Swamp	29	4	13.8
2 x 3	18	7	38.9
3 Wheedling	18	1	5.6
1 Ilred	89	45	50.6
1 x 2	101	56	55.4
2 Indiana Swamp	136	40	29.4
3 Wheedling	18	1	5.6
3 x 1	19	14	73.7
1 Ilred	89	45	50.6
362 Wisconsin 18	19	4	21.1
362 x 359	16	4	25.0
359 Dawson Golden Chaff	30	0	0.0
613 Minnesota Reliable	80	52	65.0
613 x 359	10	3	30.0
359 Dawson Golden Chaff	30	0	0.0
613 Minnesota Reliable	80	52	65.0
613 x 752	27	22	81.5
752 Nebraska 28 beardless	34	1	2.9
613 Minnesota Reliable	80	52	65.0
613 x 610	44	23	52.3
610 Michikof	22	9	40.9

considerably less hardy than the four hardiest parents. In general, then, the F_1 hybrids resembled the average of the hardier parents in cold resistance.

TABLE 2.—*Summary of winterhardiness test, 1927–28.*

Varieties and hybrids compared	Survival %	Relative survival
F_1 hybrids	33.9	100
Parent varieties	19.9	59
Hardier parents	37.4	110
Less hardy parents	7.1	21
Four hardiest parents	49.8	147
Four least hardy parents	0.0	0

The hardiness of the F_1 crosses and parental varieties grown in this winterhardiness test seems to be very closely correlated with their yield, which was reported in a previous article (8). Table 3 presents both the 1925 survival and the plant yields of those wheats which were given adequate yield tests during one or more of the years 1927, 1928, and 1929. Wherever more than one year's data were available the average is reported.

In five of the ten crosses included in this table a survival of F_1 plants greater than that of either parent was accompanied by a

correspondingly high average plant weight. In two of the crosses a survival of F_1 plants intermediate to that of the parents was accompanied by an intermediate average plant weight. Three of the crosses, i.e., 613 x 610, 611 x 613, and 611 x 615, showed a slight discrepancy in behavior. The first two of the above crosses, however, showed very high survival percentages coupled with little difference in survival between the parents, which may partially account for this small discrepancy.

As a whole, these data are fairly consistent in indicating that F_1 plants showing some degree of hybrid vigor as reflected by superior weights per plant are better able to withstand severe winters.

TABLE 3.—*Winterhardiness of varieties and F_1 hybrids of winter wheat compared with their average plant weight.*

Varieties and hybrids	Survival in 1928 %	Plant weight, grams
613 Minnesota Reliable	65.0	25.3*
613 x 610	52.3	30.4*
610 Michikof	40.9	16.7*
611 Minturki	59.1	27.1†
611 x 752	75.0	28.5†
752 Nebraska 28 beardless	0.0	18.6†
752 Nebraska 28 beardless	1.8	20.0†
752 x 614	22.9	39.9†
614 Minnesota Reliable	20.7	31.7†
1 Ilred	50.6	18.3†
1 x 2	55.5	21.9†
2 Indiana Swamp	29.4	20.8†
611 Minturki	59.1	16.9
611 x 613	68.4	17.6
613 Hardy Northern	47.6	20.5
31 Red Cross	0.0	35.4
31 x 751	8.6	55.8
751 Nebraska 28 bearded	2.3	31.5
3 Wheedling	5.6	23.0
3 x 1	73.7	52.7
1 Ilred	50.6	39.9
614 Minnesota Reliable	22.9	17.2
614 x 615	17.8	16.2
615 Michigan Amber	3.9	12.9
613 Hardy Northern	47.6	19.6
613 x 615	20.0	14.8
615 Michigan Amber	3.9	11.3
611 Minturki	75.9	17.5
611 x 615	43.1	25.6
615 Michigan Amber	2.1	11.3

*3-year average.
†2-year average.

DISCUSSION AND CONCLUSIONS

Of the 21 crosses 18 were either intermediate, more hardy than, or similar to the hardy parent in performance. Six of these hybrids were intermediate while 12 were as hardy as or more hardy than the hardier parent. Nine of these 12 were more hardy than the hardier parent. On the other hand, 3 of the 21 hybrids were as non-hardy as the less hardy parent.

These results leave the impression that winterhardiness may act as a dominant, a recessive, or a partially dominant character, depending upon the genetic composition of the varieties entering into the cross. However, when the average survival of all hardy parents was compared with the average of the F_1 hybrids, the F_1 was found to be nearly as hardy as the hardier parents.

Though the number of F_1 plants used in this experiment was relatively large it is deemed insufficient for any definite conclusion with regard to the inheritance of winterhardiness in wheat crosses.

Those crosses which exceeded the more hardy parent in degree of winterhardiness may have owed the hardiness of the F_1 to the expression of hybrid vigor in the form of resistance to adverse environmental conditions, since crosses showing hybrid vigor as measured by plant weight were also as a rule more winterhardy than the parents.

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THE EFFECTS OF SIMULATED HAIL INJURIES ON FLAX[1]

K. H. W. KLAGES[2]

Artificial injuries of plants that may be devised to simulate hail damage are at best but imitations of the real damage resulting from actual hail storms. However, since it is not possible to conjure up hail storms at desired periods in the development of plants, nor in the event of an actual hail storm to establish needed check plats, one must be contented in the study of this problem with the employment of artificial types of injuries to simulate the effects of hail on plants.

Several different types of injuries on flax will be described and their effects noted. Actual hail damage is not infrequently one of degrees and is of course not limited to any particular part of a plant, yet different intensities of hail damage may conceivably effect certain plant structures more than others. The stage of development of the plants at the time of the emergency represents an important part of a study of hail damage and extent of recovery probable.

In a section where lack of rainfall often stands out as the main limiting factor in crop production, a not too severe hail storm may not be entirely without a compensating feature insofar as such storms not infrequently bring relief from drought. Schander,[3] on the other hand, points out that the soil temperature may in the case of severe hail storms be reduced to the extent of stunting growth. There is apparently a greater probability of growth being interfered with in this manner in humid, northern naturally cool sections than further to the south or in sections with continental types of climates. Another factor to be considered is that the degree of recovery of plants, injured either by actual hail storms or by simulated hail treatments, is dependent to a great extent on climatic conditions following the infliction of injuries. All this shows that the problem of appraising hail damage in flax is, to say the least, complex and as yet lacking tangible information based on experimental results.

PLAN OF EXPERIMENT

Four distinct types of injuries were inflicted on the plants, as follows: (a) Plants were cut 1 inch above the soil line, (b) plants were whipped with a forked willow switch, (c) the leaves were

[1]Contribution from the Department of Agronomy, South Dakota Agricultural Experiment Station, Brookings, S. Dak. Received for publication December 5, 1932.

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[3]SCHANDER, R. Über Hagelbeschädigungen an Roggen, Weizen und Hafer. Fühlings Landw. Zeit., 63: 657–703. 1914.

stripped from the plants, and (d) plants were bent over at the soil line. In addition to these distinct injuries a combination of two of them, namely, stripping of the leaves and bending over of the plants, was devised.

Of these various forms of injuries the clipping of the plants was of course the most drastic and would correspond to the severest type of hail damage.

The whipping of the plants approached actual hail injury more than any other form of treatment. This treatment was especially injurious to the soft tissue of the upper portions of the stems and branches and after flowering on the flowers and the developing bolls.

At the outset it was intended that all of the leaves be stripped from the plants, but due to the extreme tenderness of the upper portions of the stems it was found very difficult to remove the topmost leaves without tearing off the growing point. This necessitated the leaving of the upper three to four leaves of the stem.

While the stems of the plants were still young and flexible, the bent over plants showed but little effect from this treatment, however, with advancing age and greater brittleness of the stems, the plants could not resume their former upright position. During the later phases of development this treatment became one of breaking rather than of bending over of the stems.

The experiment extended over a period of 3 years. No alterations were made in the types of injuries inflicted. The plants were subjected to the types of injuries described at four different stages of development in 1930, to five in 1931, and to six in 1932. These stages in 1930 were (a) plants 9 inches high, (b) buds formed, (c) at the time of full bloom, and (d) when the seed of most of the plants was in the soft dough stage. In 1931, the hard dough stage was added to these, and in 1932 the first series of injuries were inflicted when the plants were 6 inches in height. The soft dough stage here referred to designates that phase in the development of the seed when the seed is formed but when its contents are still quite soft. In the stage designated as hard dough the contents of the seed were beginning to get quite firm.

The plants were grown in rod-row nursery rows. Four replicates (five plats of each treatment) were used in the first 2 years of the test. In 1932, only three replicates were used.

Table 1 gives the dates of planting and emergence of the crop on the test plats for the 3 years of the experiment as well as the dates of the simulated hail treatments and the height of the plants previous to the infliction of the various injuries.

The season of 1930 was favorable to the growth of flax throughout; moisture was abundant and temperature relationships were favorable. The growing season of 1931 was dry and decidedly unfavorable to flax. It was cold and dry early in the season and hot

and dry during the later part of the season. The growing season of 1932 was very favorable to the crop up until shortly after the full bloom stage, but from then on it was dry and hot and as a result the flax yields were but little higher than in the previous year.

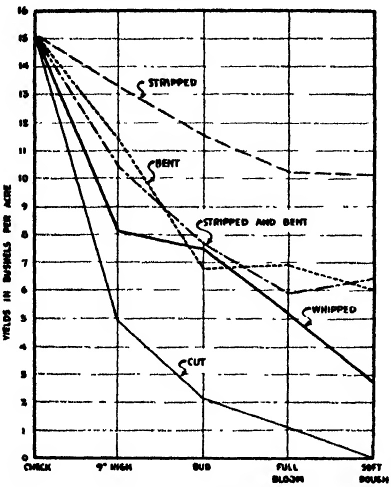

FIG. 1.—Yields in bushels per acre for the 1930 season of flax subjected to the given types of plant injuries to simulate hail damage at the different stages of development indicated.

RESULTS

Table 2 gives the yields in bushels per acre of the plats treated at the prescribed stages of development in the various manners described. Table 3 gives the percentage reduction in yield resulting from each of the simulated hail injury treatments. Figs. 1, 2, and 3 give a graphic presentation of the yield data for the 3 years of the test. The presentation of results will be facilitated by taking up each treatment separately.

TABLE 1.—*Dates of planting and emergence of the hail treatment plats in the 3 years of the test, also the dates of the simulated hail treatments and the height of the flax plants previous to the infliction of the various injuries.*

Stage of growth at the time of treatment	Planting date	Emergence date	Treatment date	Height of plants at time of treatment, inches
		1930		
	May 1	May 11		
Plants 9 inches high			June 11	8
Buds formed			June 18	14
Full bloom			June 26	22
Seed in soft dough			July 7	23
		1931		
	Apr. 20	May 1		
Plants 9 inches high			June 5	9
Buds formed			June 12	12
Full bloom			June 18	18
Seed in soft dough			June 27	20
Seed in hard dough			July 3	20
		1932		
	May 3	May 10		
Plants 6 inches high			June 8	6
Plants 9 inches high			June 14	10
Buds formed			June 20	17
Full bloom			June 27	23
Seed in soft dough			July 7	25
Seed in hard dough			July 13	25

PLANTS CLIPPED

The degree of recovery shown by flax after this most drastic treatment, as may be seen from Tables 1 and 2 and especially from Figs. 1, 2, and 3, is but slight even following clippings during the early stages of growth. Where the crop is completely cut down after having attained a height of 9 inches but little hope can be entertained for even partial recovery except under most favorable conditions. Because of the greater competition from weeds, under actual field conditions the recovery of the plants is certain to be even less than that shown by the results here given which were obtained from plats kept comparatively free from weeds.

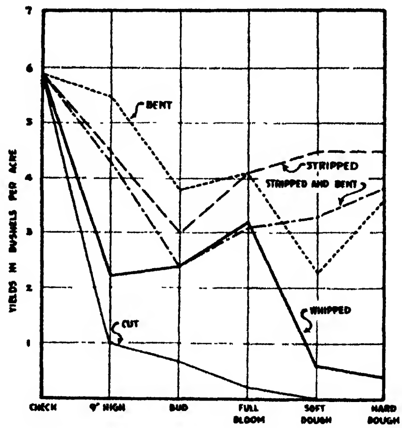

FIG. 2.—Yields in bushels per acre for the 1931 season of flax subjected to the given types of plant injuries to simulate hail damage at the different stages of development indicated.

In 1932, plats of flax were clippd at weekly intervals from the time the plants were 1 inch high on May 18 up to June 29. The yields in bushels per acre from the plats so treated were 0.5, 4.5, 2.6, 1.5, 0.3, 0.2, and 0.0, respectively, for the successive weeks. This shows that the clipping of plants, as may result from freezing, at an early stage soon after emergence is disastrous.

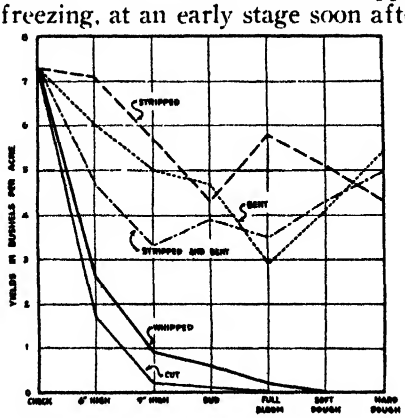

FIG. 3.—Yields in bushels per acre for the 1932 season of flax subjected to the given types of plant injuries to simulate hail damage at the different stages of development indicated.

PLANTS WHIPPED

This treatment left the plants in a condition very similar to the appearance of plants in a field after being severely hailed. Yields in all 3 years of the test were severely reduced. In all cases the damage to the plants resulting from this treatment became progressively greater with approaching maturity.

In 1932, the curve produced by the whipped plants was very much like that of the clipped plats. In the previous 2 years the plants showed a good recovery until after the full bloom stage. It was entirely possible that the whippings given the plats were more severe in 1932 than in the other seasons of the test. This treatment can readily be one of degrees.

TABLE 2.—*Yields in bushels per acre of check plats and plats subjected to various hail imitation treatments in 1930, 1931, and 1932.*

Stage of growth at time of treatment	Check	Plants cut off 1 inch high	Plants whipped	Leaves stripped from plants	Plants bent over at ground	Plants stripped and bent
			1930			
No treatment..	15.1±.30					
Plants 9 in. high	—	4.9±.11	8.1±.58	13.3±.40	11.4±.31	10.4±.17
Buds formed...	—	2.1±.02	7.5±.12	11.5±.51	6.8±.34	7.7±.38
Full bloom....	—	1.1±.01	5.2±.22	10.2±.25	6.9±.21	5.9±.33
Seed in dough .	—	0.0	2.7±.23	10.1±.29	6.0±.34	6.4±.10
			1931			
No treatment..	5.9±.08					
Plants 9 in. high	—	1.0±.08	2.2±.31	4.5±.10	5.5±.19	4.3±.10
Buds formed ..	—	0.7±.11	2.4±.11	3.0±.14	3.8±.17	2.4±.19
Full bloom.....	—	0.2±.09	3.2±.02	4.1±.24	4.1±.16	3.1±.10
Seed in soft dough......	—	0.0	0.6±.06	4.5±.21	2.3±.13	3.3±.46
Seed in hard dough.....	—	0.0	0.4±.02	4.5±.34	3.6±.19	3.8±.23
			1932			
No treatment..	7.3±.20					
Plants 6 in. high	—	1.7±.25	2.6±.14	7.1±.25	6.0±.25	4.7±.15
Plants 9 in. high	—	0.2±.04	0.9±.12	5.7±.57	5.0±.47	3.3±.27
Buds formed...	—	0.1±.01	0.6±.06	4.3±.46	4.7±.35	3.9±.42
Full bloom....	—	0.0	0.2±.05	5.8±.02	2.9±.28	3.5±.37
Seed in soft dough.	—	0.0	0.0	5.1±.33	4.1±.24	4.3±.33
Seed in hard dough.	—	0.0	0.0	4.3±.20	5.4±.69	5.0±.43

LEAVES STRIPPED FROM PLANTS

In this treatment all the leaves of the plants, except three to four on the upper very tender portions of the stems, were removed. This resulted in practically no mechanical injury to the stems of the plants. This treatment caused a smaller reduction in yield than any other. During the early stages of growth the plants were able to produce new leaves rapidly so that the vital processes were not greatly interfered with. The fact that the stem remained intact aided greatly in making possible this rapid recuperation.

The removal of the leaves from the plants is most disastrous to the flax plant, as may be seen from the tables and figures presented, when occurring at the time from bud formation to flowering. This substantiates the results reported by Dungan[4] and by Hume and Franzke[5] in their work with corn. These investigators

[4]DUNGAN, G. H. Effect of hail injury on the development of the corn plant. Jour. Amer. Soc. Agron., 20: 51–54. 1928.
[5]HUME, A. N., and FRANZKE, C. The effects of certain injuries to leaves of corn plants upon weights of grain produced. Jour. Amer. Soc. Agron., 21: 1156–1164. 1929.

found that corn was most sensitive to leaf injuries at or near the time of tasseling or shooting.

PLANTS BENT OVER

The bending over of the plants produces distinct mechanical injuries to the stems. Injuries to the stems of plants have a greater effect on yield reduction than injuries to the leaves. Most of the

TABLE 3.—*Percentage reduction in the yields of flax resulting from the various hail imitation treatments in 1930, 1931, and 1932.*

Stage of growth at time of treatment	Plants cut off 1 inch above soil	Plants whipped	Leaves stripped from plants	Plants bent over at ground	Plants stripped and bent
		1930			
Plants 9 inches high	67.6	46.4	11.9	24.5	31.1
Buds formed.......	86.1	50.3	23.8	55.0	49.0
Full bloom.........	92.7	65.6	32.5	54.3	60.9
Seed in soft dough...	100.0	82.1	32.1	60.3	57.6
		1931			
Plants 9 inches high	83.1	62.7	23.7	6.8	27.1
Buds formed.......	88.1	59.3	49.2	35.6	59.3
Full bloom.	96.6	45.8	30.5	30.5	47.5
Seed in soft dough...	100.0	89.8	23.7	61.0	44.1
Seed in hard dough .	100.0	93.2	23.7	39.0	35.6
		1932			
Plants 6 inches high	73.0	64.4	2.7	17.8	35.6
Plants 9 inches high	97.3	87.7	21.9	31.5	54.8
Buds formed.......	98.6	91.8	41.1	35.6	46.6
Full bloom.........	100.0	97.3	20.6	60.3	52.1
Seed in soft dough ..	100.0	100.0	30.1	43.8	41.1
Seed in hard dough..	100.0	100.0	41.1	26.0	31.5

plants bent over previous to the bud stage were again able to resume an upright position, but even then this treatment resulted in a material reduction in yields. The bending over of the plants at full bloom may result in a yield reduction of from 30 to 60%. Yield reductions increased progressively up to the soft dough stage.

PLANTS STRIPPED AND BENT

The yield reductions produced by a combination of the removal of the leaves and the bending of the plants are very much like those resulting from the bending over of the plants alone. It is noticeable, however, that greater yield reductions result, as is to be expected, from this combination of injuries during the early phases of the development of the plants than from the bending over of the plants alone. The yield data given show clearly that injuries to the stems of the plants are far more detrimental than to the leaves.

SUMMARY

Four distinct types of plant injuries devised to simulate hail damage were inflicted on flax plants during six stages of development.

Clipping of plants 1 inch above the level of the soil resulted in very severe yield reductions. Plants clipped after the 6- and 9-inch stages showed practically no recovery.

Whipping of flax plants with a branched willow switch produced a good semblance of actual hail damage. Plants subjected to this form of injury prior to the full bloom stage showed a fair degree of recovery.

Plants recuperated rapidly from a removal of practically all of their leaves during the early phases of growth. Leaf injuries produced most evident detrimental effects during the bud and flowering stages.

Bending over of the plants caused severe reductions in yields in all but the very early phases of development.

The results presented indicate that mechanical injuries to the stems of flax plants led to materially greater reduction in yield than injuries or even removal of the leaves.

The degree of recovery from any type of plant injury is dependent to a large measure upon climatic conditions following the infliction of the injuries.

SOIL ORGANIC MATTER REQUIREMENTS IN GENERAL FARMING[1]

A. W. Blair[2]

Dr. Chas. E. Thorne (5),[3] in his paper on "The Function of Organic Matter in the Soil," published in this Journal in September, 1926, carefully reviewed the long-time experiments at Rothamsted, Pennsylvania, Ohio, Indiana, and Missouri, and while it is not necessary to report at length on this review, it may be well to re-state a few of his conclusions and suggestions as to practical applications.

It should be remembered that Dr. Thorne limited his discussion to what he considers ordinary farm crops. He would treat as a separate proposition truck crops and other crops of high acre value.

In his summary Dr. Thorne points out that considering duration of test, the yield of wheat on plat 8, Broadbalk Field, Rothamsted

[1]Contribution from the Department of Soils and Crops, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication November 29, 1932.

[2]Soil Chemist.

[3]Reference by number is to "Literature Cited," page 548.

(complete fertilizer treatment) is the largest of which the world has any record. This record yield has been obtained without the introduction of organic matter other than that contained in roots and stubble of the crops grown. At Wooster, Ohio, the yields from plat 8, which has received chemicals only, have been above the average yields for the county in which the test is located, notwithstanding the fact that the soil was very poor at the start. In this experiment corn grown continuously on plat 6, with 5 tons of manure annually, has fallen off as rapidly as that on land which received chemical fertilizers.

For a period of 40 years at the Pennsylvania Experiment Station yields of corn, oats, wheat, and clover were maintained as well by chemicals as by manure. Dr. Thorne does not believe that either chemicals or manure possess any regular superiority in unfavorable weather. He finally calls attention to the fact that the work which he has reviewed shows that it is possible by the use of chemicals alone to maintain the yields of farm crops for periods of 20 to 70 years on a parity with the yields from applications of farm manures containing much larger total quantities of the essential chemical elements, and further, that the addition to the land of any organic matter for the sake of carbonaceous material which it may contain is altogether unnecessary. He holds that the larger root growth which may be obtained as effectively from the elements in chemicals as from those in manure furnishes all the organic carbon required for bacterial functioning.

Dr. Thorne recognizes that, as a matter of course, soils high in organic carbon are fertile soils and that the distribution of decaying vegetation through the soil favors its physical condition, but he believes the fact has been too generally overlooked that no artificial distribution of vegetation through the soil is so perfect as the natural growth of plant roots, and that when sufficient nitrogen and mineral elements have been supplied in available form, and the water supply properly regulated, the plant will find all the carbon required and with its roots will take care of the soil's physical condition.

This brief review of Dr. Thorne's paper is given because it has a bearing on results secured over a period of 25 years at the New Jersey Agricultural Experiment Station. The experiment was planned for the purpose of studying the relative availability of a number of nitrogenous materials. Among these were farm manure, nitrate of soda, and calcium nitrate. In the work reported here, mineral fertilizers (phosphoric acid and potash) were applied to all plats alike. The soil was moderately acid when the work was started, and therefore a limed and unlimed series of plats was provided. The entire experiment embraces 20 plats in the limed section and 20 in the unlimed section. Only four plats from each section are under consideration in this paper.

The rotation as originally planned was 1 year of corn, 2 years of

oats, 1 year of wheat, and 1 year of timothy.[4] At the end of the first 5 years it was decided to change the rotation so that there would be 1 year of oats and 2 years of timothy. Cow manure was applied to certain plats at the rate of 16 tons to the acre annually. The standard application of nitrate of soda was 320 pounds to the acre, and an equivalent amount of calcium nitrate was used. The soil is a loam lying just where the Coastal Plain begins and therefore is more closely related to the Sassafras than to the Penn series, which lies just north of the Sassafras. For some time previous to 1908, when the first crop was grown, the land had been uncultivated and neglected.

FERTILIZER AND MANURE TREATMENT

The fertilizer and manure treatment for the plats under consideration is as follows:

5A and 5B—Minerals and manure.
9A and 9B—Minerals and nitrate of soda.
10A and 10B—Minerals and nitrate of lime.
18A and 18B—Minerals, nitrate of soda, and manure.

In reporting yields, only the hay and grain are included, the stalks, straw, and cobs being omitted. The yields of grain and hay for the 25-year period are shown in Table 1 (16 years of grain and 9 years of hay).

An examination of the averages shows that there is but little difference between the yields from the limed and unlimed sections. There are probably two or three reasons for this. In the first place, the rotation includes no legumes, and the crops grown are not especially sensitive to an acid soil. In the second place, both the manure and the nitrates have a favorable effect on acid soils. Both nitrate of soda and nitrate of lime have a slight corrective effect when used continuously on an acid soil. Manure may not actually neutralize the acidity, but it has a corrective effect so far as crop growth is concerned. Finally, certain weeds, such as the daisy (*Chrysanthemum leucanthemum*), the mayweed, (*Anthemis cotula*), and wild carrot (*Daucus carota*), were much worse on the limed than on the unlimed plats. Had clover been introduced in the rotation, the yields of hay on the limed section would have told a different story.

Considering first the unlimed section, it will be noted that the average yields of grain and hay for plat 5A, where manure is used as the only source of nitrogen, are only a few hundred pounds more than the average yields for 9A and 10A, where nitrate of soda and nitrate of lime, respectively, are used. However, the cost of the manure at market price would be far more than the value

[4]This rotation was chosen because it was necessary to have nonlegume crops in studying the relative availability of nitrogenous fertilizers. It is not recommended under present conditions.

TABLE 1.—*Yields of grain and hay in pounds with complete fertilizer in comparison with complete fertilizer and manure, 1908–1932.**

Plat No.	1908–1912		1913–1917		1918–1922		1923–1927		1928–1932		Total dry matter		Yearly average	
	Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay	Grain	Hay
Unlimed Section														
5A	7,101	2,575	4,740	8,720	4.240	9,650	5,931	10,793	5,572	6,384	27,584	38,122	1,724	4,236
9A	6,227	3,325	4,065	7,760	4,068	7,360	4,812	7,496	4,412	6,411	23,584	32,352	1,474	3,595
10A	5,619	3,300	3.410	7,740	3,908	7,760	4,600	7,097	4,016	4,720	21,553	30,617	1,347	3,402
18A	7,390	4,875	5,560	8,700	5,256	9,660	6,230	12,791	6,364	7,475	30,800	43,501	1,925	4,833
Average	6,584	3,519	4,444	8,230	4,368	8,608	5,393	9,544	5,091	6,248	25,880	36,148	1,618	4,017
Limed Section														
5B	6,385	1,850	3,695	7,180	3,885	7,560	4,620	5,521	3,731	3,706	22,316	25,817	1,395	2,869
9B	5,903	2,850	3,555	6,540	4,000	8,000	4,750	7,083	3,978	5,778	22,186	30,251	1,387	3,361
10B	6,646	3,250	4,515	7,680	4,638	9,060	5,971	8,146	4,955	6,340	26.725	34,476	1,670	3,831
18B	7,467	5,875	5,870	8,720	5,930	10,180	6,354	12,837	6,188	7,138	31,809	44,750	1,988	4,972
Average	6,600	3,456	4,409	7,530	4,613	8,700	5,424	8,397	4,713	5,741	25,759	33.824	1,610	3,758

*Fertilizer treatments on an acre basis, as follows:
5A and 5B—Minerals (640 lbs. superphosphate and 320 lbs. muriate of potash) and 16 tons of cow manure.
9A and 9B—Minerals and 320 lbs. nitrate of soda.
10A and 10B—Minerals and calcium nitrate equivalent to 320 lbs. nitrate of soda.
18A and 18B—Minerals, 320 lbs. nitrate of soda, and 16 tons of cow manure.
The minerals were reduced to half the amount indicated beginning in 1923.

of the increase in yield of grain and hay. In other words, with manure as the source of nitrogen, the increase in yield is bought at too great a price.

Comparing the yields from plat 18A, where both manure and nitrate of soda were used, with the yields from plats 9A and 10A, where the nitrates were used, it will be noted that the average increase in grain due to the manure for the 16 years amounted to about 500 pounds a year, and that the increase in hay for the 9 years amounted to about 1,334 pounds a year. In this case, if the manure had been purchased at the market price, the increased yields would probably not have paid one-fourth of the cost. Furthermore, the hay from the manured plats contained many weeds which must either be pulled before cutting the hay or left to give an inferior quality of hay.

The story for the limed section, as already intimated, is quite similar to that of the unlimed section, though even more favorable to the system of chemical fertilizers. Here the average yield of grain and hay for the nitrate plats (9B and 10B) was more than the yield on 5B, where manure was used as the only source of nitrogen. For plat 18B, where both manure and nitrate of soda were used, the 16-year average yield of grain was nearly 500 pounds more than the corresponding average for the two nitrate plats (9B and 10B) and the yield of hay was nearly 1,400 pounds more. But here again the increased yield secured by the manure would fall far short of paying the cost.

WILL CHEMICAL FERTILIZERS MAINTAIN YIELDS?

Dr. Thorne has effectively answered this question in the affirmative by his reference to the long-time work at Rothamsted. It may not be amiss, however, to call attention to the results secured in the experiment under consideration. The total yields for the 5-year period of 1913–1917, the first 5-year period being omitted on account of change in rotation, may be compared with the total yields for 1928–1932. The average yield of grain for the two nitrate plats on the unlimed section (1913–1917), was 3,738 pounds, while the corresponding yield for the period of 1928–1932 was 4,214 pounds. The corresponding figures for the limed section are 4,035 pounds of grain for 1913–1917 and 4,467 pounds for the period of 1928–1932. The yields of hay were not quite maintained during the last period, but this is due largely to the fact that there was a shortage of rain during the two hay seasons of 1931 and 1932.

INFLUENCE OF THE MANURE ON THE SOIL

It is of interest to find out what has been the effect of the manure on the chemical composition of the soil. According to determinations made in 1909, the soil where this experiment is located contained at the time the work was started about 0.11% nitrogen and

1.2% of total carbon. Analyses made in 1928 show that where manure has been used continuously, the nitrogen has been increased to about 0.134% and the total carbon to about 1.7%, while the nitrogen and carbon on the plats that receive chemical fertilizers have remained about constant or decreased slightly. However, the increase which has been brought about on the manured plats has been at a great loss of nitrogen. Comparing the original analyses with the 1928 analyses from the manured plat, it will be seen that this gain amounts to 0.024%. On the basis of the plowed acre, this would mean a total of 480 pounds, or just short of 20 pounds annually for the 25 years. The annual application of nitrogen to this plat, including manure and nitrate of soda, has been more than 200 pounds to the acre, while the crops removed would scarcely account for an average of 50 pounds to the acre.

With heavy applications of decomposable organic matter to the soil, large losses of nitrogen are to be expected. Russell (1) estimates a loss of nearly 70% of the added quantity of nitrogen from Broadbalk Field, Rothamsted, where manure was used at the rate of 14 tons to the acre annually. Then he adds, "Unfortunately, on our present knowledge it is impossible to maintain a high content of nitrogen on cultivated land except at a wasteful expenditure of nitrogenous manures." And just here it is pertinent to raise the question as to whether, under conditions of general farming, it is necessary to raise materially the level of nitrogen and organic matter in the soil. In the Middle Atlantic States, where the rainfall is high, certainly the level of fertility is not high. The total nitrogen is frequently not over 0.10 to 0.14%, and total carbon (organic) may range from less than 1 to 1.5%. Yet, in productivity these soils compare favorably with the corn and wheat soils of the middle western states which have been under cultivation a much shorter period and which have been looked upon as fertile because they were rich in organic matter.

ROTATION WITH LEGUMES

Alongside the experiment in which the 5-year rotation included only nonlegume crops is another 5-year rotation where legumes are included. The rotation is 1 year each of corn, oats, and wheat and 2 years of timothy and clover. In this work it has been the practice to seed a cover crop of vetch and clover at the last cultivation of the corn and also to seed a green manure crop of soybeans following the oats and wheat. Unfortunately, the cover crop in the corn has usually been more or less of a failure.

Provision was made for the use of both calcium and magnesian limestone at the rate of 1,000, 2,000, and 4,000 pounds to the acre once in 5 years, and a check plat without lime.

All plats received the same fertilizer treatment annually, about as follows: For nonlegume crops a nitrogenous fertilizer has been

used to give the equivalent of about 200 pounds of nitrate of soda to the acre. For legume crops little or no nitrogen has been used Superphosphate has been used at the rate of 300 pounds to the acre and muriate of potash at the rate of 50 to 100 pounds to the acre. The lime treatments are as follows: Plat 21, no lime; plats 22, 23, 24, calcium limestone at the rate of 1,000, 2,000, and 4,000 pounds to the acre, respectively, at 5-year intervals; and plats 25, 26, and 27, a like treatment with magnesian limestone.

The work was started in 1908 and thus the crop for 1932 completes results over a period of 25 years. The yields of grain and hay by 5-year periods are shown in Table 2.

TABLE 2.—*Grain and hay (timothy and clover) in pounds from a 5-year rotation, with different lime treatments.**

Plat No.	1908–1912	1913–1917	1918–1922	1923–1927	1928–1932	Total dry matter	Annual average
21	5,670	8,970	6,936	6,593	5,831	34,000	1,360
22	6,182	11,085	10,996	11,631	11,531	51,425	2,057
23	6,699	12,700	12,136	14,556	14,193	60,284	2,411
24	7,088	13,075	12,738	14,169	15,702	62,772	2,511
25	8,181	12,270	12,700	14,449	14,335	61,935	2,477
26	8,180	14,075	13,806	15,144	16,206	67,411	2,696
27	7,992	14,420	14,428	15,339	17,018	69,197	2,768
Ave ..	7,142	12,371	11,963	13,126	13,546	58,146	2,326

*Plat 21, no lime. At intervals of 5 years plats 22, 23, and 24 received 1,000, 2,000, and 4,000 lbs., respectively, of calcium limestone, and plats 25, 26, and 27 a like application of magnesian limestone.

The figures bring out several points of interest. Taking the averages for the 25 years, it will be noted that the yields increase with increase in the amount of lime. The increase in yield of hay is much greater than the increase in grain.[5] It will be observed also that, while the 4,000-pound application of limestone gives an increase over the 2,000-pound rate, this increase is not sufficient to justify the use of the additional ton.

Taking plats that have received what may be considered a fair amount of lime, that is, 1 ton of the limestone to the acre, the total yield for the 25 years has been greater than the total yield where a complete fertilizer was used in the nonlegume rotation. Furthermore, the fertilizer treatment in the rotation with legumes has cost less than the treatment in the nonlegume rotation.

If the yields from the plats which receive 1 ton of limestone to the acre in the rotation with legumes be compared with the yields from the plats which receive a complete fertilizer and 16 tons of manure to the acre in the nonlegume rotation, it will be found that the annual difference is only 463 pounds to the acre in favor of the manured plats.

[5]Grain and hay are not shown separately in the table.

The average yield of grain for the last 5-year period is greater than the corresponding average for the first 5-year period, and the average yield of hay for the last 5-year period is over three times as much as the average for the first 5-year period. Thus it is established that yields have been increasing under this system.

It must be made clear here that this is not an attempt to disprove the value and importance of organic matter for soil improvement. The question at issue is, will crop residues accumulated in general farming supply sufficient organic matter to give maximum economical yields, other conditions being favorable? The results obtained in the two experiments described point conclusively to an affirmative answer for the type of soil under consideration.

The value of organic matter for improving the physical condition of the soil, for increasing its water-holding capacity, for furnishing plant-food in a slowly available form, and as a source of energy material for soil organisms should not be overlooked. However, the work reported by Thorne, and in this paper, leads to the conclusion that in general farming crop residues may be depended upon to supply an adequate amount of organic matter, provided the soil is in normally good physical condition.

Vegetable growing, fruit growing, and other specialized types of farming present a different problem and may require an entirely different treatment, but even here much can be done to maintain the supply of organic matter by utilizing all crop residues and growing green manure crops whenever possible.

In many cases soils have been allowed to become depleted of organic matter because they were too acid to grow legume crops, and because there was an inadequate supply of readily available nitrogen. Correct the acidity and legumes, if given a chance, begin immediately to build up the content of organic matter. Supply available nitrogen, and nonlegume crops grow well.

But, as Russell has said, it is impossible to maintain a high percentage of nitrogen, and this implies organic matter also, in the soil, except at a great loss of nitrogenous fertilizer. On the subject of gains and losses of nitrogen, Russell (2) calls attention to the fact that land under grass which was not disturbed for summer fallow continued to gain nitrogen, but he adds, "The accumulation of nitrogen thus brought about does not go on indefinitely; in course of time an equilibrium is reached, higher or lower according to the soil conditions, where further gains are balanced by losses, so that the nitrogen content remains constant." The nitrogen cannot be increased except as the carbon is increased. Russell (3) again says, "Purely nitrogenous fertilizers, such as nitrate of soda, sulfate of ammonia, dried blood, etc., add no nitrogen to the soil beyond what corresponds with any carbon added by the stubble." Results at the New Jersey Agricultural Experiment Station show that there may even be losses of nitrogen from cropped soils in spite of added nitrogenous fertilizer.

If in fertilizer practice, we will insist on meeting fully the mineral and nitrogen requirements of the crop, making allowance for losses, and see that the soil does not become over acid for the crops to be grown, and that some legumes are included in the rotation, there need be no great anxiety about the supply of organic matter.

In this connection Sievers and Holtz (4) state that, "High crop production to be permanent requires practices that maintain the soil nitrogen and such practices will then also automatically maintain the soil organic matter, provided the mineral constituents are present in adequate amounts."

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EFFECT OF FERTILIZERS ON THE YIELD OF RICE GROWN IN POTS[1]

JENKIN W. JONES[2]

The production of rice on a commercial scale in California is a comparatively new industry. Even so, yields decrease rather rapidly when the crop is grown continuously on the same land. This probably is due to (a) competition with weeds, (b) to a deficiency in one or more elements of plant food, or (c) to unfavorable changes in the physical and biological nature of the soil, owing to continuous submergence of the land.

On rice lands that are well drained during the winter and summer months the productive capacity of the soil is materially improved by fallowing for one or more years. If, following the fallow year, a crop of bur clover is plowed under during seedbed preparation in the spring, high yields of rice usually are obtained.

Rice grown continuously on the same land at the Biggs Rice Field Station, Biggs, Calif., did not maintain yields at a high level, even when kept free of weeds and fertilized with the three common

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plant food elements, nitrogen, phosphorus, and potassium, either singly or in combinations. This indicates that reduced yields are probably due to induced unfavorable changes in the physical, chemical, and biological nature of the soil incident to continuous submergence of the land year after year.

REVIEW OF LITERATURE

The literature on the fertilization of rice soils is rather extensive. Citations in this paper are restricted to results obtained from studies in the Hawaiian Islands and the United States.

Kelley and Thompson (8),[3] in chemical analyses of the rice plant at different stages of development, have shown that fertilizers should be applied at an early period in the life cycle, because the rice plant when two-thirds grown has taken up 80% or more of the total nitrogen, phosphorus, and potash that is absorbed to maturity. Of the nitrogenous fertilizers tested by Krauss (9, 10) and by Kelley (6, 7) in Hawaii, ammonium sulfate gave the best results. This fertilizer also produced higher yields than applications of phosphorus and potash. Kelley (7) also reports that with a sufficient organic matter content ammonification in a submerged soil is rapid enough to supply the nitrogen needs of rice.

Laude (11) and Reynolds and Wyche (14) obtained increased yields of rice in Texas from land fertilized with cottonseed meal, manure, phosphoric acid, and ammonium sulfate. Of these fertilizers, ammonium sulfate gave the best results. Quereau (13), Chambliss and Jenkins (1), and Jenkins (3), in Louisiana, failed to obtain important increases in the yields of rice by applying fertilizers. Under certain conditions each of the plant nutrients, nitrogen, phosphorus, and potash, appeared to be beneficial, but the increases in yields were neither consistent nor profitable. Nelson (12) reports decreased yields in Arkansas from all fertilizers except nitrogen derived from a combination of ammonium sulfate and cottonseed meal. In Arkansas and Louisiana (12, 13) the highest yields of rice have been obtained by growing the crop in rotation with soybeans and on fallow land. Jones (4, 5) and Dunshee (2) found in California that all fertilizers, except lime, increased the yields of rice. Ammonium sulfate gave the best results. A good growth of bur clover plowed under during preparation of the seedbed usually increases yields of rice in California.

MATERIALS AND METHODS

Experiments were started at the Biggs Rice Field Station in 1927 to study the effect of fertilizers applied singly and in combinations on the yield of rice grown in pots. These studies were conducted for three seasons in a coarse screened inclosure a short distance

[3]Reference by number is to "Literature Cited," p. 554.

from submerged land. The screened inclosure protected the plants from birds.

In 1927 the experimental rice was grown in soil in galvanized cans 12½ inches in diameter and 14 inches deep, painted inside with Oronite roof paint. Six cans were used for each fertilizer treatment. Three galvanized cans and three clay crocks, the latter 12 inches in diameter and 14 inches deep, were used for each fertilizer treatment in 1928 and 1929. Fifty pounds of well-mixed Stockton clay adobe surface soil were placed in each can and 45 pounds in each crock. The soil used in 1927 had been fallowed in 1926, that used in 1928 had been fallowed for 2 years (1926 and 1927), and the soil and the pots used for the 1929 crop were the same as those used in 1928.

Each year the soil in all containers received similar cultural treatment. In the fall, after harvest, the containers were turned over to provide drainage and to prevent water-logging. In the spring they were placed in an upright position and in the same order as in previous years.

Caloro rice was used in these experiments. The seed used each year came from a single plant. In 1927, the seed was partly germinated by soaking in water before it was sown on May 9. On May 16, 1928, and on April 26, 1929, the soil in the pots was submerged and the seed was sown in the water. Shallow water, 1 to 2 inches deep, was held in the pots until the seedlings had emerged and had become well anchored in the soil. The water was then increased in depth to about 4 inches and held at this depth until the rice was ready to drain preceding harvest. Unless otherwise stated, six plants were grown to maturity in each pot.

In 1927, water from a well was added to the pots each morning to replace that lost by evaporation and transpiration, whereas in 1928 and 1929 water was added on alternate mornings.

The rice was harvested at maturity by cutting the plants off near the ground. The total air-dry weight of the plants harvested from each pot was determined. The weight of the grain after threshing was subtracted from the total weight to obtain the weight of straw.

FERTILIZER APPLICATIONS

Ammonium sulfate was applied at the rate of 150 pounds per acre and the other nitrogenous fertilizers were used in quantities that supplied a like amount of nitrogen, except in the case of bur clover. Bur clover, consisting of green stems, leaves, and burs, was applied at the rate of 2 tons of green material per acre. On the basis of 0.5% of nitrogen, this was an application of approximately 20 pounds of nitrogen per acre, or nearly two-thirds the amount applied in ammonium sulfate. Potassium sulfate was applied at the rate of 100 pounds and superphosphate at the rate of 350 pounds per acre. When more than one fertilizer was applied,

each was used at the same rate as if applied alone. Each year the fertilizers were applied and mixed with the surface inch or two of soil. The soil in the pots was then submerged and the rice was sown in the water.

There was a good deal of variation in height of plant, number of culms, and yield of grain and straw within the replicated pots of each treatment. In 1928 and 1929, in most cases, the height, number of culms, and the yield of grain and straw of plants grown in crocks were less than those of plants grown in cans. There was much more variation with respect to numbers of culms and grain and straw yields in nearly all treatments when the rice was grown on fallowed soil than when grown on soil cropped the previous year. The average number of culms and the average yields of grain and straw were much higher in 1927 and 1928 than in 1929. This also shows the effect of previous fallow or crop.

Data on height, number of culms, and yield of grain and straw of rice grown in the experiments during the 3-year period are shown in Table 1. The tallest plants, the largest number of culms, and the highest grain and straw yields were produced by plants grown in soil fertilized with bur clover. On the other hand, the shortest plants, the smallest number of culms, and the lowest grain and straw yields were produced by plants grown in soil fertilized with potassium nitrate.

TABLE 1.—*Mean height, number of culms, and yield of grain and straw of rice grown in the fertilizer experiments for the 3-year period 1927 to 1929, at Biggs, Calif.*

Fertilizer treatment	Height, inches	Number of culms	Grain, grams	Straw, grams
Control	188.1±1.90	38.8±0.74	66.4±1.43	69.0±2.86
Bur clover	198.8±1.74	49.4±1.08	83.2±1.88	85.8±2.53
Ammonium sulfate	189.5±1.96	42.1±1.08	66.7±2.63	77.8±3.21
Dried blood	191.6±1.82	39.2±0.71	66.3±1.43	72.2±1.95
Cottonseed meal	190.0±1.65	40.8±0.68	65.8±1.37	75.9±2.55
Calcium cyanamid	191.9±1.55	42.9±0.90	69.3±2.04	75.3±2.82
Potassium nitrate	187.7±1.07	38.1±0.57	64.0±1.73	60.4±1.85
Potassium sulfate	188.1±1.31	38.7±0.57	67.3±1.10	63.5±1.21
Superphosphate	185.4±0.94	42.5±1.01	66.5±1.26	68.2±1.96
Ammonium sulfate, Potassium sulfate	192.1±1.13	43.2±0.93	68.8±1.71	77.6±1.69
Ammonium sulfate, Superphosphate	194.9±2.31	45.6±0.97	75.1±1.45	82.7±2.40
Ammonium sulfate, Potassium sulfate, Superphosphate	196.1±1.82	45.5±1.09	74.3±1.17	81.3±1.61
Potassium sulfate, Superphosphate	187.4±2.07	43.4±0.88	67.9±1.04	73.2±1.19

The plants grown in soil fertilized with bur clover were 5.7% taller than the check plants; those grown in soil with a complete fertilizer, 4.3% taller; and those grown in soil fertilized with a combination of ammonium sulfate and superphosphate, 3.6% taller. The average grain yield of plants fertilized with bur clover, a

combination of ammonium sulfate and superphosphate, or a complete fertilizer was considerably higher than the yield of the check plants. The average increase in number of culms varied from 1% for plants grown in soil fertilized with dried blood to 27.3% for those grown in soil fertilized with bur clover.

Increases in average grain yields varied from 0.5% for the plants grown in soil fertilized with ammonium sulfate to 25.3% for those grown in soil fertilized with bur clover. Increases of 10% or more in the yields of grain were obtained from plants grown in soil fertilized with calcium cyanamid, ammonium and potassium sulfate, ammonium sulfate and superphosphate, potassium sulfate and superphosphate, and a complete fertilizer. In general, the fertilizers that produced the largest grain yields also produced increased straw yields.

The ratio of grain to straw varied from 1 : 0.94 for plants grown in soil fertilized with potassium nitrate to 1 : 1.15 for plants grown in soil fertilized with cottonseed meal. All plants grown in fertilized soil, except those receiving potassium nitrate and potassium sulfate, produced slightly more straw than grain.

Variability was greater for some fertilizer treatments than for others. The greatest variation in height was in plants grown in soil fertilized with a combination of ammonium sulfate and superphosphate, whereas the least variation in height was in plants grown in soil fertilized with superphosphate. The number of culms varied most in plants receiving a complete fertilizer and least in plants fertilized with potassium nitrate. Yields of grain and straw were most variable in plants grown with ammonium sulfate.

Bur clover was the only fertilizer that produced plants significantly taller than those of the check. Grain yields from this fertilization also were significantly higher.

The germination and early growth of the rice was retarded in pots fertilized with bur clover. The decomposition of the clover under water probably resulted in the formation of gases that retarded germination and normal root development. Once established, however, the plants grew rapidly and each year were more vigorous and had a better appearance than the check plants or the plants grown in soil fertilized with other materials. Maturity of the rice fertilized with bur clover was delayed as much as 2 days. Other fertilizers delayed maturity by only a day, or not at all.

Three seed lots, consisting of 100 seeds, were weighed from the produce of each fertilizer treatment in 1927 and 1928. None of the plants grown in fertilized soil produced seeds appreciably heavier than those of the check plants. In fact, in 1927, only plants grown in soil fertilized with dried blood produced seed that was as heavy as that of the check plants. In that season seed from plants grown with ammonium sulfate and potassium nitrate was 2.7% lighter than that from check plants. In 1928, a combination of ammonium sulfate and potassium sulfate, ammonium sulfate, or potassium

nitrate produced plants with seed as heavy as or slightly heavier than that of the check plants, all others producing lighter seed. Seed from plants grown with a combination of ammonium sulfate and superphosphate was 5.4% lighter than that of the checks. Under the conditions of this experiment none of the fertilizers consistently increased the weight of the seed.

DISCUSSION

The conditions under which these experiments were conducted were not comparable to field conditions, as the pots had no drainage. Results indicate that moderate drainage is beneficial to the growth and yield of rice. The pots were located on dry ground and were surrounded by a much drier atmosphere and at times by higher temperatures than exist in a submerged field. In addition, they were too small to accommodate an extensive root development. This latter factor in particular was a distinct disadvantage in cases where the fertilizers stimulated root development. Although the pots each contained 45 or 50 pounds of soil, they were practically root bound at the end of the first crop year. This fact may account in part for the low grain yields of 1929 as compared with those of 1927 and 1928. Yet, in spite of all handicaps, the data tend to confirm results obtained in California in field plat experiments with fertilizers.

The fertilizers were applied, the soil was submerged, and the seed was sown in the water. It is possible that some nitrogen was lost as a gas before the plants were well enough established to utilize nitrogen. It requires from 3 weeks to a month for seed rice to germinate in and for the seedlings to emerge through from 4 to 6 inches of water. This probably is long enough for nitrates to be reduced under anaerobic conditions with a consequent loss of nitrogen. It seemed possible in 1927 that some zinc from the galvanized cans had entered into solution and interfered with the growth of the plants. However, the results obtained when the clay crocks were used in 1928 and 1929 indicate that this was not serious, as grain yields were higher, as a rule, in the cans than in the crocks.

Probably the main reasons why ammonium sulfate, dried blood, and cottonseed meal increased the yields of rice in pots to a lesser degree than they have in field plats were the drier atmosphere surrounding the pots—a body of soil too small to permit proper aeration and root development—and a possible accumulation of toxic substances in the undrained soil.

SUMMARY

All plants grown in fertilized soil were slightly taller than the check plants, except those grown in soil fertilized with potassium nitrate and potassium sulfate. The average increase in the height of plants grown in soil fertilized with bur clover and a complete

fertilizer, respectively, appears to be significant, whereas the other increases and decreases in height are probably not significant.

All plants grown in fertilized soil produced more culms than did the check plants, except those grown in soil fertilized with potassium nitrate and potassium sulfate. The average increase in number of culms ranged from 1% in plants grown in soil fertilized with dried blood to 27.3% in plants grown in soil fertilized with bur clover.

What appear to be significant increases in grain yields weie obtained from a combination of ammonium sulfate and superphosphate, a complete fertilizer, and bur clover. The average increases in the order given were 11.9, 13.1, and 25.3%, respectively.

The plants in all treatments, including the check, produced slightly more straw than grain, except those grown in soil fertilized with potassium nitrate and potassium sulfate. The ratios of grain to straw varied from 1 : 0.94 in plants grown in soil fertilized with potassium nitrate to 1 :1.15 in plants grown in soil fertilized with cottonseed meal. None of the plants grown in fertilized soil produced seed significantly heavier than that of the check plants.

The application of bur clover resulted in the largest yields of rice, whereas superphosphate, potassium sulfate, and potassium nitrate applied alone had no appreciable effect upon yield.

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TESTS WITH IMPORTED SEED OF *VICIA VILLOSA*[1]

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Vicia villosa seed is imported under the common name of hairy vetch. Since the fall of 1929, samples of import lots of this seed have been grown at Arlington Farm, Rosslyn, Virginia; Corvallis, Oregon; and Athens, Georgia. The object was to determine the varietal forms represented in the various lots. This study has shown that imported seed of *V. villosa* produces two morphological forms of plants. One form is characterized by heavy or very noticeable pubescence throughout and by having leaf and flower buds seemingly imbricated and thickened or clustered at the end of the stems. This latter characteristic is especially noticeable during the active growth period and until the plants are in full bloom. This is the form of *V. villosa* most commonly known as hairy vetch and the writers suggest that the name be continued for this form. The other form does not have the leaf and flower buds noticeably clustered at the ends of the stems and appears almost glabrous. The name smooth vetch has been used for this, and it is suggested that this name be generally adopted.

Tabulations have been made for each year showing the number of import samples that were pure hairy vetch, the number that were pure smooth vetch, the number that were about equally mixed, and the number of mixed in which one form predominated (Table 1). Data bearing on the rate of early growth are tabulated from the results of the import lot plantings at Arlington Farm, Rosslyn, Virginia, for the years 1929, 1930, and 1931 (Table 2).

It will be noted that the lots composed entirely of the hairy form made less winter growth at Arlington Farm than smooth vetch or the mixed lots. In the case of the mixed lots, the height of the tallest growth of the mixture, regardless of whether it was smooth vetch or hairy vetch, was taken as the height of the planting. A study of the lots of pure smooth vetch and of pure hairy vetch showed considerable variation of winter growth within these forms. In general, smooth vetch made stronger winter growth than hairy vetch, but some lots of hairy vetch made as strong winter growth as the best smooth vetch. Most of the hairy vetch from extreme northern regions made slower winter growth than similar vetch from farther south. No smooth vetch seed were imported from the extreme north while both smooth and hairy vetch seed were represented in lots from more southern regions.

[1]Contributed cooperatively by the Oregon Agricultural Experiment Station, Corvallis, Ore.; the Agronomy Division, Georgia State College of Agriculture and Mechanic Arts, Athens, Ga.; and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Received for publication December 8, 1932.

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The results of these tests indicate that both smooth vetch and hairy vetch seed are imported under the name hairy vetch. It is further indicated that hairy vetch seed is produced in the more northern regions while seed of both smooth vetch and hairy vetch is produced in more southern areas. In general, smooth vetch

TABLE 1.—*Tests with import lots of Vicia villosa seed showing number of lots and proportion of smooth and hairy vetch.*

Import year	Hairy vetch		Smooth vetch		About 50% each	Grand total
	Entirely	Mostly	Entirely	Mostly		
1929. . .	68	13	13	33	9	136
1930. . . .	20	13	2	24	15	73
1931 . .	25	15	13	23	10	86

TABLE 2.—*Tests with import lots of Vicia villosa seed, showing average height in inches in early spring, Arlington Farm, Rosslyn, Virginia.*

Import year	Hairy vetch		Smooth vetch		About 50% each	Notes taken
	Entirely	Mostly	Entirely	Mostly		
1929. . .	5.13+	5.5	6.92+	6.7—	7.0	Apr. 5, 1930
1930 . . .	5.89+	7.0	7.0	7.38—	6.73—	Apr. 22, 1931
1931. . .	4.08—	4.64+	4.62—	4.5	5.0	Feb. 29, 1932

will make a stronger winter growth in the southern states than hairy vetch. This latter statement is in keeping with general observations made of commercial plantings of *V. villosa* in the cotton belt. It is suggested that more attention be paid to the source and type of *V. villosa* seed intended for use for green manuring in the southern states.

NOTE

SYMPTOMS OF PHOSPHORUS DEFICIENCY IN TURKISH TOBACCO

In the past few years at the Kentucky Agricultural Experiment Station, Turkish tobacco has been grown extensively in water, sand, and soil cultures in the greenhouse in a study of "frenching" of tobacco where deficiencies of various nutrients, including phosphorus, existed. In the cultures deficient in phosphorus, this nutrient was removed from, or very much reduced in, the medium fairly early in the growth of the plants or else, particularly in the soil cultures, was deficient during the entire growth period.

Phosphorus deficiency is shown by characteristic symptoms or habits of growth in the plants. Johnson (U. S. D. A. Bul. 1256), McMurtry (U. S. D. A. Tech. Bul. 340), and Morgan (Jour. Amer. Soc. Agron., 21: 132) have described these as observed by them in various kinds of tobacco.

The effects observed in the Kentucky experiments were somewhat more varied than those described by any one of the preceding writers. They were as follows: (1) an abnormal dark green color with easily noticeable dusky tinge; (2) the lack of bulging between the veins of

FIG. 1—Turkish tobacco plants, showing spotting due to phosphorus deficiency. The plants at the left were grown in soil from the Greenville soil experiment field; those at the right in sand.

the leaves; (3) in general, the spindling appearance of the plants due to the small stem and leaf petioles in proportion to size of leaves and, particularly, to height of plants; and (4) the development of spots on the leaves on the lower part of the plant when phosphorus was deficient enough, and even the death of the leaves, the lowest dying first and then progressively up the stalk.

When first observed the spots appeared like water-soaked areas. They were of diverse shape and likely to develop any place on the leaves on the lower one-half to two-thirds of the plant, generally only a few per leaf but of considerable size. A number measured were from a few mm to 20 mm across and increased very little in size after they were first observed. In the beginning, the spots were distinguishable from the surrounding tissue only by a slightly darker color and by the depression of the two surfaces below the normal leaf surfaces, due to partial collapse of the tissues of the diseased areas. In a comparatively short time, sometimes only a few hours, the spots dried out and became a light brown to brown color. Fig. 1 shows typical spots.

Frequently the death of leaves was brought about by the breakdown in the basal part of the leaf of the midvein and usually some part of the immediate leaf area and side veins, this often extending farther in and directly along the side veins rather than in the leaf area in between. Occasionally a yellowing with brownish tinge

preceded the dying of leaves where apparently phosphorus was the only nutrient deficiency. Continuation of terminal plant growth with dying of the lower leaves at the same time was quite marked in some of the experiments where phosphorus was deficient. Four such plants in a water-culture experiment had an average height of 56 cm when flower buds appeared. At this time about the lower one-third of the leaves had dried and spotting had developed above in the lower half of the remaining leaves. In certain soil-culture experiments, phosphorus-deficient plants formed no seed, the flower parts dropping off at about the time of blooming.

Considerable spotting and some dying of leaves developed on plants in the soil-culture experiments where phosphorus-deficient soils from the Berea, Greenville, Campbellsville, and Mayfield soil experiment fields were used. (See Ky. Agr. Exp. Sta. Bul. 322 for soil treatment and management of these fields.) The observations made, however, have not shown this development in tobacco grown in the field at these soil experiment fields.—P. E. KARRAKER and C. E. BORTNER, *Kentucky Agricultural Experiment Station, Lexington, Ky.*

BOOK REVIEW

CHROMOSOMES AND PLANT BREEDING

By C. D. Darlington. New York: Macmillan Co. XIV+112 pages, illus. 1932. $1.75.

In this book the author presents to the plant and animal breeder a clear and fluent account of the fundamentals of cytogenetics which has been much needed. Since the text states somewhat dogmatically the conclusions which the author arrived at in his book *Recent Advances in Cytology*, readers should remember that not all cytologists entirely agree with him. (For a detailed criticism of Darlington's *Recent Advances in Cytology*, see J. Belling's Critical Notes in Univ. of Calif. Pub. in Bot., 17, 5:75–110. 1933.) Although strict accuracy is lacking in parts, the book as a whole should be both enjoyable and valuable to breeders in general.

A foreword by Sir Daniel Hall briefly outlines the purpose of the book. The first chapters are devoted to a simple description of the cytological detail necessary to an understanding of the subject, such as the microscopical image of the cell, the process of mitosis, the somatic chromosomes, the constancy of their number, size, and shape, processes of fertilization, and reduction.

The practical importance of apomixis is pointed out. The reduction division is shown in relation to the laws of inheritance in that the parental chromosomes "recombine both as between different chromosomes by their passing at random to the two poles and as between different parts of the same chromosome by crossing over." The qualitative genetical influence of individual chromosomes and parts of chromosomes, chromosomal variants, fragmentation, and segmental interchange are considered.

The remainder of the book is devoted to polyploidy. Non-hybrid tetraploidy shifts the 3:1 ratio of diploid recessive segregation to 35:1. A simple diagram (Fig. 14) shows why hybrid tetraploidy may lead to lack of segregation. "Doubling in a pure species reduces fertility by encouraging irregularities in segregation, doubling in a hybrid restores fertility simply by abolishing segregation so far as it can abolish it." A list of 18 hybrid tetraploids is discussed. The practical inference is drawn that, "If a breeder raises a sterile hybrid which is of no use to him, let him look out for the odd seed which will give him his new race, a giant and fertile polyploid."

Polyploid species are described. When a new polyploid species arises in nature, dwarf seedlings may appear in the first generation. Thus, in *Prunus cerasus* (4x) and *Solanum nigrum* (6x) the polyploid has taken a dwarf type as compared with its diploid relatives. The polyploid speciation of *Triticum*, *Aesculus*, *Rubus*, *Galeopsis Spartina*, *Primula*, *Oenothera*, *Campanula*, and *Tulipa* is discussed. Chapter XIII on Breeding with Polyploids describes how polyploid species may be detected genetically, how polyploids are more stable when subjected to x-ray than diploids, and how fatuoid types crop out in hexaploid oats due to ring formation of chromosomes at reduction division. The genetical behavior of *Triticum polonicum* x *T. durum*, *Primula floribunda* x *P. verticillata*, *Fragaria chiloensis* x *F. virginiana* offspring is used to prove the advisability of crossing polyploids (Chapter XIV).

Triploidy (Chapter XVI), while frequently leading to infertility, has produced forms of commercial importance. Flowering cherries, triploid watercress, many tulips, hyacinths, pears, and apples are mentioned in this connection. Diploid apples and pears are considered as secondary polyploids which have originated from ancestors with 2 x 7 chromosomes. "This earlier set at a remote period was doubled in part and triplicated in the other part." *Dahlia Merckii* is considered to have arisen similarly.

The book concludes with the following paragraph: "While chromosome studies therefore do not give the plant breeder any greater control over his material, they enable him to direct his efforts into the right channels for obtaining and preserving the results likely to prove most profitable to him." (B.R.N.)

AGRONOMIC AFFAIRS

PROGRAM OF THE CROPS SECTION

The programs for two sessions of the Crops Section of the Society at the Annual Meeting in November are still open to contributors, but titles of papers must be submitted prior to October 1 to be assured of a place. Those having papers to submit for consideration are requested to communicate with the Chairman of the Section, Dr. Merle T. Jenkins, Iowa Agricultural Experiment Station, Ames, Iowa, giving the title and a brief summary of the paper and the time desired for presentation.

A MEMORIAL TO DR. GEDROIZ

The January-February issue of *Chemisation of Socialistic Agriculture* is devoted entirely to accounts of the life and work of the late Dr. K. K. Gedroiz, former president of the International Society of Soil Science. The following articles are included in the number: K. K. Gedroiz as Agro-chemist, by D. N. Projanischnikow; K. K. Gedroiz as a Pedologist, by A. N. Sokolobsky; K. K. Gedroiz as a Scientist, by E. V. Britzke; Gedroiz's Doctrines and Perspectives of Their Development, by A. Th. Tuelin; Problems of Liming the Soil in Gedroiz's Teachings, by O. K. Kedrov-Sichman; Theory of Alkali Soils and Gedroiz's Doctrine, by F. N. Germanov; Gedroiz as Soviet Scientist and Teacher, by E. Magaram; Gedroiz and Experimentation, by S. P. Kuljinsky; and Pot Culture Methods in Gedroiz's Research Work, by Y. G. Haranovskaya. All of the articles have a brief summary in English.

A complete list of Dr. Gedroiz's published works is also appended, together with a review of his latest book on "Chemical Analyses of Soils." The Institute of Fertilizers is now known as the Gedroiz Scientific Research Institute of Fertilizers and Agronomical Soil Science. Dr. Gedroiz's widow was pensioned by the Commissariat of Agriculture and a fellowship has been established in his name.

PLANNED COUNTY DEVELOPMENT

Standardized commercial production of farm crops and livestock is one of the main objectives of the Sumter County (South Carolina) 10–year agricultural development program formulated by Stanley F. Morse, formerly professor of agriculture and director of extension of the University of Arizona and for the past 17 years a consulting agriculturist. This 10-year program is using the basic facts secured by the recently completed agricultural economic survey of Sumter County made by the South Carolina Experiment Station.

The results of this economic study, made by Messrs. Jensen, Russell, and Guin, are embodied in South Carolina Experiment Station Bulletin 288, which goes into detail as to cultural methods for various crops and sets up standards for the growing of each of the major crops. To supplement the economic survey a new soil survey is now being made of Sumter County.

Included in the 10-year program are projects for the production of certified farm seeds, peavine hay for market (in connection with which South Carolina State standards for cowpea hay have been established for the first time), cotton standardization (to reduce the number of varieties to two or three), sweet potato improvement (to meet market requirements), truck crop production, and soil fertility maintenance.

This program was started over a year ago and the various projects are in charge of committees of farmers under the direction of Professor Morse and the county agent. The purpose of this planned development is to stabilize the agriculture of the county on a profitable basis.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 SEPTEMBER, 1933 No. 9

LODGING IN SMALL GRAINS[1]

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Lodging in small grain is generally recognized as a source of loss. Where a high state of soil fertility is maintained, the prevention of lodging may be a serious problem. Soil management systems which are desirable from the standpoint of crop yields and soil fertility often increase the probability of lodging of the small grain crops.

An accurate evaluation of the resistance of various varieties to lodging is difficult. Abundance of rainfall and relatively high temperature, weather conditions which commonly are associated with the production of weak straw, do not occur every season. Wind storms, which provide a critical test of lodging resistance, occur at irregular intervals. Hence, adequate testing of varieties necessarily requires several years of observation.

The results reported in this paper were obtained through an investigation of certain morphological characters in wheat and barley which might be related to lodging behavior. The work involved the relation between tillering and lodging in wheat and barley, and the relation between breaking strength of culms and lodging in wheat.

REVIEW OF LITERATURE

The strength of culms in small grains and other grasses has been attributed to many causes. Sir Humphrey Davy (3),[3] in 1798, believed the silicon content of "the epidermis of hollow plants" to be a factor in strength of plant. Liebig (8) likewise stressed the importance of potassium silicate in the stems of grass plants. However,

[1]Contribution from the Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 1153 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication December 10, 1932.

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[3]Reference by number is to "Literature Cited," page 572.

Welton and Morris (14) pointed out that much of the silica found in the grasses is contained in the leaves rather than in the culms.

Purvis (11), studying orchard grass (*Dactylis glomerata* L), concluded that potassium salts aided in strengthening the culms. Tubbs (13) noted that potassium starvation decreased the crushing strength of the lower nodes of barley culms.

Palladin (9) and Percival (10) noted the weakening effect of thick planting with its resulting shading and etiolation.

Welton and Morris (14) have given an extensive review of literature regarding the environmental conditions associated with lodging. In their own studies, these investigators reported that lodging in wheat and oats was associated with low content of dry matter per unit length of culms and with etiolation due to shading. They attributed the latter condition to heavy seeding and to the use of varieties which tiller freely. They found that the stiff-strawed varieties produced fewer tillers than weak-strawed types when the plants were spaced 8 inches apart each way.

Garber and Olson (5) investigated the anatomy of oats, wheat, barley, and rye and found none of the morphological characters studied, except thickness of cell walls, was closely related to lodging. They concluded that lodging was dependent upon so many factors of unequal value in the different sorts that no one factor seemed to be correlated closely enough to be of much value as a selection index, although both the early and medium oat strains examined showed a distinct correlation between thickness of lignified cell walls and lodging.

A number of investigators have studied the breaking strength of straw in relation to lodging. Willis (15) and Helmick (7) described apparatus for such tests. Salmon (12) studied the breaking strength of winter wheat varieties. He found that the soft winter wheat varieties which are noted for lodging resistance generally showed the highest breaking strength, while the hard winter wheats, which lodge easily, showed the lowest breaking strength. While he obtained high correlation between the breaking strength of straw of various winter wheat varieties in different seasons, he was unable to show highly significant correlations between breaking strength and lodging for the years studied. Welton and Morris (14) found that the breaking strength of eight varieties of winter wheat correlated closely with the lodging performance over a period of years.

Davis and Stanton (2) in oat studies reported that, "In general, the reputed stiff-strawed varieties as determined by field observations, when subjected to a mechanical straw strength test, showed the highest resistance to breaking."

EXPERIMENTAL METHODS

RATE OF TILLERING

Studies of tillering were made with 24 varieties of spring wheat and 17 varieties of barley grown in the varietal test plats at University farm in 1931. Each variety was grown in 1/40 acre, triplicate, randomized plats. The hard spring wheats were seeded at the rate of 90 pounds to an acre and the durum wheats at 105 pounds per acre. Barley was seeded at the rate of 96 pounds per acre.

When the plants were in the seedling stage and before tillers had formed, three areas of 1 square yard each were measured in each plat and the plants within the areas counted. From these data the number of plants to an acre was calculated. The areas were carefully marked with stakes so that counts could be made in the same areas at a later date. At maturity the culms were counted and the increase in number of culms was used as a measure of the amount of stooling that occurred.

BREAKING STRENGTH OF WHEAT CULMS

One hundred culms were harvested from each wheat plat. The bundles were hung in a dry room for 8 weeks and samples of each variety used in the breaking tests.

The tests were made with a special dynamometer designed by Holdefleik and Stephany and manufactured by Paul Polikeit, Halle, Germany (Fig. 1). Each culm was tested individually by laying it in a horizontal position across two supports placed 6 cm apart and applying a force to the middle of the culm through a hook attached to a cord and weight. The force was applied in a vertical direction, at a right angle to the length of the culm. The first internode above the ground was used for the breaking tests and the leaf sheath was removed. The force required at the instant of breaking was recorded in grams. Ten culms were taken at random from each plat sample for a total of 30 culms from each variety.

A vernier caliper was used to measure the diameter of each culm at the point of breaking. These measurements were recorded in millimeters.

LODGING INDICES

The lodging index for each variety was obtained by multiplying the percentage of plants lodged by the angle at which the culms were inclined. Since no lodging occurred in the varietal trials at University Farm in 1931, the lodging indices were taken from the rod row nursery trials at four Minnesota stations, *viz.*, University Farm, Crookston, Morris, and Waseca, for an average of the 3 years 1928–30. As lodging occurred in the 1/40 acre varietal trials at Morris in 1930, a comparison was made with these data.

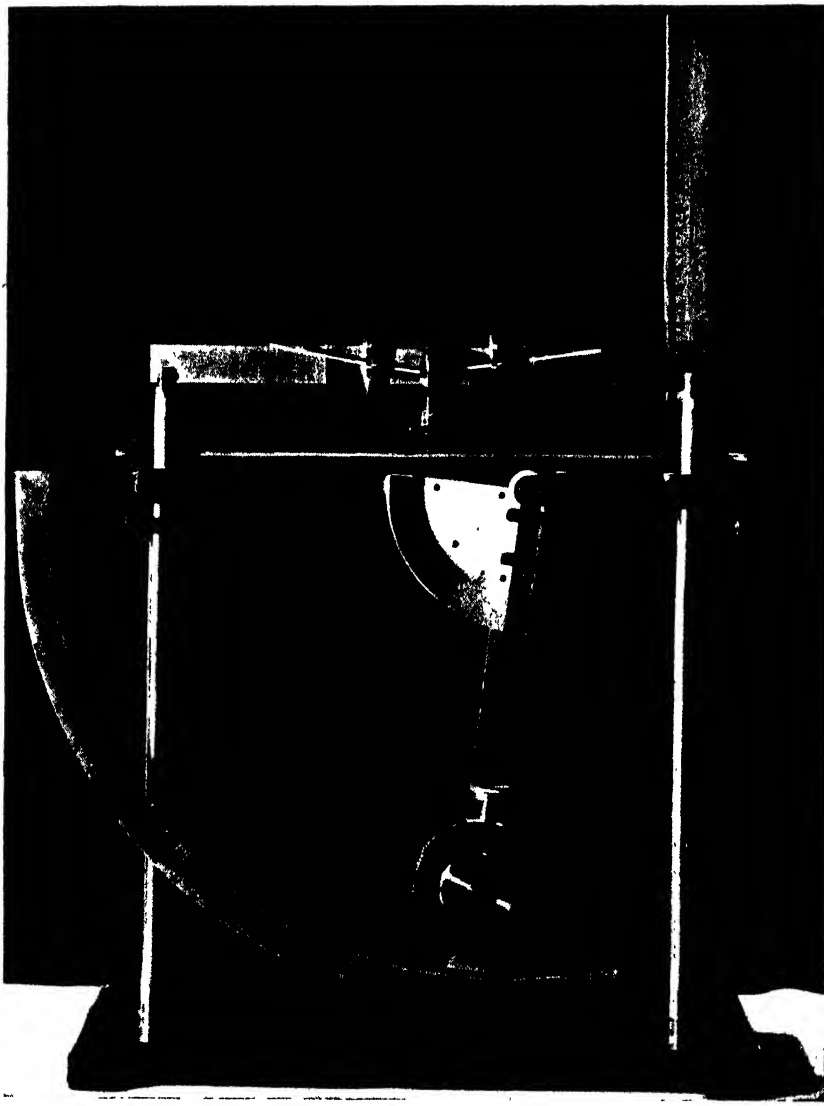

FIG. 1.—Straw-breaking machine used in testing strength of wheat and barley culms.

COMPUTATIONS

The probable errors used for comparisons of tillering of wheat and barley and for breaking strength of wheat were calculated by the variance method described by Fisher (4). The methods outlined by Hayes and Garber (6) were used for calculating gross and partial correlations.

EXPERIMENTAL RESULTS

TILLERING OF WHEAT

The number of plants per acre, culms per acre, and average number of tillers per plant in each of the 24 wheat varieties are presented in Table 1.

TABLE 1.—*Number of plants and culms per acre and tillers per plant of spring and durum wheat varieties grown in 1/40 acre plats, University Farm, 1931.*

Variety	Minn. No.	Plants per acre (000 omitted)	Culms per acre (000 omitted)	Tillers per plant
	Common Wheat			
H-44	Acc. 2301	682	1,923	2.82
Marquillo	2202	707	1,860	2.63
Double cross II—21-81	2338	764	1,994	2.61
Double cross II—21-47	2305	784	2,023	2.58
Double cross II—21-92	2339	824	2,028	2.46
Double cross II—21-84	2316	767	1,879	2.45
Hope	Acc. 2297	719	1,740	2.42
Double cross II—21-42	2304	786	1,840	2.34
Kota x Marquis 1656-48	Acc. 2317	692	1,619	2.34
Reward	Acc. 2204	868	1,961	2.26
Double cross II—21-7	2302	822	1,832	2.23
Double cross II—21-48	2315	813	1,812	2.23
Supreme	Acc. 2309	840	1,848	2.20
Double cross II—21-94	2340	893	1,929	2.16
Marquis	Acc. 1239	810	1,693	2.09
Double cross II—21-28	2303	908	1,843	2.03
Reliance	Acc. 2308	782	1,533	1.96
Ceres	Acc. 2223	864	1,668	1.93
Kota x Marquis 1656-85	Acc. 2298	822	1,561	1.90
Bluestem	169	878	1,572	1.79
Kota x Marquis 1656	Acc. 2224	872	1,526	1.75
	Durum Wheat			
Nodak	Acc. 2311	848	1,526	1.80
Kubanka	Acc. 2310	947	1,496	1.58
Mindum	470	878	1,344	1.53

The analysis of variance consists of calculating the sums of squares due to replicates, varieties, and total, and obtaining that for error by subtraction. The sums of squares divided by the degrees of freedom gives the mean square of calculated variance. The analysis which follows is for tillering:

Variation due to	Degrees of freedom	Sums of squares	Mean squares	Value of Z
Replicates	2	0.6077	.3038	
Varieties	23	8.2306	.3579	1.1401
Error	46	1.6862	.0366	
Total	71	10.5245		

The value of Z was calculated by obtaining ½ $\log_e$ of the quotient of the mean square for varieties divided by the mean square for

error. The calculated value of Z for the above determination of tillering rate in wheat varieties, in which $N_1 = 23$ and $N_2 = 46$ was 1.1401. In Fisher's (4) table of 1% points for the distribution of Z with $N_1 = 24$ and $N_2 = 30$, the points most nearly approaching the corresponding values in this analysis, the value of $Z = .4519$. Hence the differences in tillering of the wheat varieties were highly significant. However, it should be noted that the number of plants per acre differed widely, there being 682,000 plants of H-44 to an acre and 947,000 plants of Kubanka per acre. Accordingly, it is important to determine if the differences in tillering are due to differences in stand or to varietal response. The test for this is the correlation coefficient.

Gross and partial correlation coefficients were calculated for tillering and stand in two replicate series. The results are given in Table 2.

TABLE 2.—*Correlations between tillering and stand in series I and series II of wheat varietal plats.*

	Tillering, series I	Tillering, series II	Stand, series I
Tillering, series II.........	.6907±.0720		
Stand, series I	—.7741±.0552	—.7529±.0504	
Stand, series II.	—.4218±.1132	—.7024±.0697	.5177±.1008

The gross correlations between tillering and stand in these series are highly significant. The gross correlation between tillering in series I and tillering in series II, likewise, is significant. However, the partial correlation between tillering in series I and tillering in series II, holding constant the stand, is only .05. Evidently the differences in tillering were the result of differences in stands and were not due to any genetic differences among the varieties. These differences in stands may have been due to variations in the rates of seeding. Since the plats were sown at a uniform rate by weight and since the varieties varied somewhat in size of seed, the number of seeds sown on a given area may have varied considerably. Variations in the tillering reaction may have compensated for the differences in stand.

Welton and Morris (14) found that one group of stiff-strawed varieties of winter wheat averaged 8.9 culms per plant, while another group of weak-strawed varieties averaged 10.7 culms per plant. These determinations were made with plants spaced 8 inches apart each way. Obviously these are not comparable with tillering studies made with plants sown at a uniform rate by weight in 6-inch drill rows.

No lodging occurred in the varietal plats at University Farm where these studies were made as drought conditions prevailed from heading time until harvest. Most of these varieties had been grown at the West Central Station at Morris in 1930, and distinct

varietal differences in lodging had been recorded. A comparison of lodging indices of 16 varieties of common wheat in the 1930 trials at Morris and the tillering behavior of the same varieties in the present study is given in Table 3.

TABLE 3.—*Comparison of tillering rates in 16 varieties of common wheat at University Farm in 1931 and lodging indices of the same varieties at Morris in 1930.*

Variety	Tillers per plant	Lodging index
H-44	2.82	14.4
Marquillo	2.63	0.5
Double cross II—21-47	2.58	14.4
Double cross II—21-84	2.45	8.1
Hope	2.42	5.4
Double cross II—21-42	2.34	10.3
Kota x Marquis 1656-48	2.34	7.1
Reward	2.26	0.6
Double cross	2.23	15.6
Double cross II—21-48	2.23	14.2
Supreme	2.20	0.4
Marquis	2.09	1.3
Reliance	1.96	3.1
Ceres	1.93	1.1
Kota x Marquis 1656-85	1.90	11.0
Kota x Marquis 1656	1.75	16.1

The gross correlation between lodging and tillering was only .1107. Obviously this is wholly lacking in significance.

TILLERING IN BARLEY

The number of plants and culms per acre and the average number of tillers per plant for the barley varieties grown at University Farm are given in Table 4. In each case the data are averages of three plats of each variety.

TABLE 4.—*Number of plants and culms per acre and tillers per plant of barley varieties grown in 1/40 acre plats, University Farm, 1931.*

Variety	Minn. No.	Plants per acre (000 omitted)	Culms per acre (000 omitted)	Tillers per plant
Heinrich's	465	800	2,281	2.82
Parent Mech. Mixture	—	730	1,986	2.72
Svanhals x Lion	474	683	1,638	2.40
Svanhals x Lion	475	735	1,735	2.36
Manchuria x Smooth Awn	457	806	1,725	2.14
Composite cross	—	711	1,458	2.05
Smooth Awn x Manchuria	462	785	1,390	1.77
Trebi	448	715	1,259	1.76
Glabron	445	876	1,515	1.73
Colsess	Acc. 461	794	1,246	1.57
Peatland	452	1,109	1,697	1.53
Minsturdi	439	754	1,124	1.49
Wisconsin Barbless No. 38	Acc. 529	878	1,273	1.45
Velvet	447	1,005	1,437	1.43
Jeans	—	891	1,212	1.36
Svansota	440	1,097	1,459	1.33
Manchuria	184	897	1,175	1.31

Analysis of variance for tillering was as follows:

Variance due to	Degrees of freedom	Sums of squares	Mean squares	Value of Z
Replicates	2	0.5131	.2565	
Varieties	16	11.0097	.6881	3.1564
Error	32	1.1700	.0366	
Total	50	12.6928		

The calculated value of Z for the determination of tillering rate in barley varieties, in which $N_1 = 16$ and $N_2 = 32$, was 3.1564. In Fisher's (4) table of 1% points for the distribution of Z, the value of $Z = .5224$ with $N_1 = 12$ and $N_2 = 30$. It is evident that the differences in tillering of the barley varieties were highly significant. This is corroborated by the tests for correlation given in Table 5.

TABLE 5.—*Correlations between tillering and stand in series I and series II of barley varietal plats.*

	Tillering, series I	Tillering, series II	Stand, series I
Tillering, series II.........	.9109±.0279		
Stand, series I............	—.6199±.1007	—.4488±.1307	
Stand, series II.	—.5372±.1164	—.4481±.1309	.6685±.0905

The gross correlations between tillering in duplicate series of plats, between stands in duplicate series, and between tillering and stand are within accepted limits of significance.

When stand is held constant in series I and series II, the partial correlation between tillering in series I and series II was 0.8976 ± .1143, indicating a highly significant correlation. Hence it appears that the barley varieties differed significantly in rate of tillering, and that these differences were not the result of variations in stand.

The probable error for the average tillering rate of three plats of one variety, as given in Table 4, is 4.08%. The probable error for Heinrich's, the variety with the highest tillering rate, is 2.82 x .0408 = .115. Multiplying $.115 \times 3 \times \sqrt{2} = .60$ and subtracting $2.82 - .60 = 2.22$. The odds are approximately 45 to 1 that all varieties with a tillering rate of 2.22 or less differ significantly from Heinrich's. The data indicate that 13 varieties had a lower tillering rate than Heinrich's.

STRENGTH OF WHEAT CULMS

The average breaking strength and diameter of 10 culms selected at random from each variety of wheat of three plats of each for a total of 30 culms per variety are given in Table 6.

TABLE 6.—*Comparison of average breaking strength and average diameter of culm of wheat varieties, average lodging index of the same varieties in rod row trials at four stations, 1928–30, and lodging index in varietal trials at Morris in 1930.*

Variety	Breaking strength of culm, grams	Diameter of culm, mm	Lodging index, av. of 4 stations 1928–30	Lodging index, Morris 1930
		Common Wheat		
Kota x Marquis 1656 48	717	2.86	20.8	7.1
Kota x Marquis 1656 .	617	2.87	22.0	16.1
Kota x Marquis 1656 -85	612	2.73	—	11.0
Bluestem	606	3.16	—	—
Double cross II—21–42	603	3.11	37.6	10.3
Supreme.	601	3.13	—	0.4
Ceres . . .	595	2.88	77.9	1.1
H-44	581	2.69	20.5	14.4
Marquis.	576	2.89	14.0	1.3
Double cross II—21–92	521	2.80	29.0	—
Double cross II—21–84	505	2.95	55.4	8.1
Marquillo . . .	500	3.10	10.9	0.5
Double cross II—21 -81	480	2.94	39.4	—
Hope	480	2.82	31.6	5.4
Double cross II—21 28	471	2.56	—	—
Reward . .	465	2.89	—	0.6
Double cross II—21–94	454	2.70	32.0	—
Reliance.	453	2.80	—	3.1
Double cross II—21 48	452	2.80	45.9	14.2
Double cross II—21–7	440	2.67	37.1	15.6
Double cross II—21 -47	437	2.67	39.3	14.4
		Durum Wheat		
Mindum.	733	3.10		33.0
Nodak	690	3.00		38.4
Kubanka.	641	2.86		40.3

Analyses of variance in breaking strength of varieties and of diameter of culms were calculated to determine whether the varieties differed significantly in these two characters. The analysis of variance in breaking strength was as follows:

Variation due to	Degrees of freedom	Sums of squares	Mean squares	Value of Z
Replicates	2	1.02	.5100	
Varieties	20	5.43	.2715	.4402
Error	40	4.50	.1125	
Total	62	10.95		

The analysis of variance in diameter of culms was as follows:

Variation due to	Degrees of freedom	Sums of squares	Mean squares	Value of Z
Replicates	2	.17	.085	
Varieties	23	1.86	.081	.3917
Error	46	1.69	.037	
Total	71	3.72		

The analysis of variance in breaking strength shows that the calculated value of Z is .4402, which is close to the 1% point as given in Fisher's (3) table. Hence, the varietal differences are considered significant. The probable error for the average of 10 determinations for each of the three plats of one variety is 2.37%. The probable error in grams forKota x Marquis 1656–48 is 717 x .0237 = 17 grams. Multiplying 17 x 3 x $\sqrt{2}$ = 88, and subtracting 717 — 88 = 629. Since the odds are approximately 45 to 1 that varieties with breaking strength of 629 grams or less are significantly lower than Kota x Marquis 1656–48, the data indicate that this variety differs significantly from all other varieties tested.

The analysis of variance in diameter of culms gives a calculated value of Z = .3917 which is beyond the 5% point in Fisher's table. Hence, it is evident that the varieties differed significantly in diameter of culm. The calculated correlation between breaking strength and diameter of culm was .537 ± .148. Since the correlation is approximately three times as great as the probable error, it may be considered significant.

These results confirm the conclusion of Salmon (12) that breaking strength can be determined with a fair degree of accuracy. However, unless it is found that breaking strength is associated closely with lodging behavior, such determinations are of doubtful value.

BREAKING STRENGTH AND LODGING

Fifteen of the common wheat varieties used in the breaking strength determinations had been tested in the rod-row nursery at four Minnesota stations for 3 years, 1928–30. The average lodging indices are given in Table 6. It will be noted that lodging performance as shown by these data is not closely associated with breaking strength as determined in the 1931 trials. Ceres, with an average lodging index of 77.9, had approximately the same breaking strength as H-44, which had a lodging index of 20.5. Marquillo, noted for its stiff straw and lodging resistance, had an average lodging index of 10.9 in 12 trials (3 years at four stations), but showed a breaking strength of 500 grams, which was below the mean (551 grams) of the 24 varieties. These observations were confirmed statistically by calculating the correlation between breaking strength and lodging as shown in these data. The result, —.1799, is not significant.

Using the lodging data obtained for 16 common wheat varieties at Morris in 1930 (Table 6), another comparison may be considered. The correlation between breaking strength and lodging from these data was .0602. As in the comparison with lodging data from the nursery trials, no significant correlation was found.

It is recognized that these data for lodging are not conclusive since they were not obtained from the same plats from which breaking strength determinations were made. But even data for

the same season could not be depended upon to give an accurate comparison of varieties as to lodging resistance, for wind storms which cause lodging might not strike all plats with equal intensity. Observations of lodging over a period of years would be necessary. The state of growth at which weather causing lodging occurs also affects the tendency of varieties to lodge, as Salmon (12) has pointed out. He found interannual correlations in the same varieties to be low. Nevertheless, the above comparisons between breaking strength and lodging data indicate the inaccuracy of the assumption that breaking strength and lodging resistance are synonymous.

The three durum varieties included in the study present an interesting anomaly. Compared to common varieties, durum wheats have higher breaking strength and greater diameter of culm, fewer tillers, and less lodging resistance. Thus, higher breaking strength is found associated with lower lodging resistance. This may be due to the greater weight of head and longer culm in the durum plant. Albrecht (1) found breaking strength strongly correlated with weight of head and weight of culm in winter wheat. It is evident that a complete evaluation of the relationship between breaking strength and lodging must consider weight of head, length and weight of culm, and perhaps elasticity of culm in the complex of factors involved.

SUMMARY

Rates of tillering were studied in 24 varieties of spring and durum wheat and 17 varieties of barley grown in the 1/40 acre varietal plats at University Farm, St. Paul, Minn., in 1931. No differences in the tillering rates of wheat plats were found which could be attributed to genetic differences in the varieties, since the variance between the average tillering rates was not statistically significant. However, a study of the partial correlation between tillering rates in series I and tillering in series II, holding stand constant, indicated that differences in tillering were associated with differences in stand. It is suggested that these differences in stand may have been due to differences in the number of seeds sown on unit areas, since the plats were sown at uniform rates by weight and the varieties varied somewhat in size of seed. No correlation was found between the tillering rates of wheat varieties in these trials and the lodging behavior of the same varieties at Morris in 1930.

The 17 varieties of barley differed significantly in rates of tillering. These differences in tillering were not entirely associated with differences in stand. It is believed that these differences may be genetic.

The breaking strength of wheat culms was determined by breaking 10 culms from each of the three plats of each variety. The

differences in breaking strength were found to be significant. The correlation coefficient between breaking strength and diameter of culm was .537 ± .148.

The breaking strength of the varieties as determined in these trials was compared with the lodging behavior of the same varieties at Morris in 1930 and at four Minnesota stations in 1928, 1929, and 1930. No correlation was found between breaking strength and lodging in either of these comparisons.

Three durum varieties included in the study had higher breaking strength, greater diameter of culm, and lower tillering rate than the common wheat varieties.

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THE DETERMINATION OF THE NUMBER OF SAMPLES NECESSARY TO MEASURE DIFFERENCES WITH VARYING DEGREES OF PRECISION[1]

J. R. LIVERMORE AND WINSTON NEELY[2]

In 1911, Wood[3] presented a formula to facilitate the calculation of the number of plats or other units required to attain any desired degree of precision of measurement for any experiment. The formula is based on the derivation of the probable error of a mean (PE_m) f om the relationship of the probable error of a single determination (PE_s) to the total frequency (n), namely, $PE_m = \frac{PE_s}{\sqrt{n}}$.

Since much agronomic research is concerned with the significance of the difference between two means and since it is not always possible to predict which of the means will be the greater, Wood's original formula will be modified in order that it may be more generally applicable to any situa'ion.

The probable error of a difference (PE_D)is equal to the square root of the sum of the squared errors of each of the two means, as follows:

$$PE_{D_{A-B}} = \sqrt{(PE_A)^2 + (PE_B)^2}$$

It may be assumed that the errors of the two means will not be greatly different each from the other, so the equation may be written $PE_D = \sqrt{2}\ PE_M$.

The mathematical significance of the difference (D) is estimated by the magnitude of the ratio of the difference to its probable error, or $\frac{D}{PE_D}$.

Whatever level of significance this ratio must attain is purely arbitrary and may be decided by the individual. However, as a matter of fact, odds of 30:1 are rather commonly accepted as indicative of mathematical significance. The D/PE_D ratio necessary for odds of approximately 30 : 1 is 3.17. In other words, the difference must be slightly more than three times its probable error.

The general formula to determine the number of units necessary to measure a certain difference with any desired degree of precision is developed as follows: Since $PE_D = \sqrt{2}\ PE_M$, then $\frac{D}{PE_D} = \frac{D}{\sqrt{2}\,PE_M}$;

and since $PE_M = \frac{PE_s}{\sqrt{n}}$, then $\frac{D}{PE_D} = \frac{D}{\sqrt{2}\frac{PE_s}{\sqrt{n}}}$; and since $\frac{D}{PE_D}$ =

[1]Paper No. 191, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Received for publication December 10, 1932.

[2]Assistant Professor of Plant Breeding and Assistant in Agronomy, respectively.

[3]Wood, T. B. The interpretation of experimental results. Jour. Bd. Agr., London, Sup. 7: 15-37. 1911.

ratio, then ratio $\sqrt{2}\ PE_s = \sqrt{n}\ D$ and $n = \left(\frac{\text{ratio } \sqrt{2}\ PE_s}{D}\right)^2$.

The probable error of a single plat or other unit as used in this formula is in percent of the mean but expressed as a natural number. If the PE_s is 11% of the mean, 11 would be substituted for PE_s in the formula. A similar rule applies to the term D or the difference to be measured in the problem. If an 18% difference is to be measured, then 18 would replace D. To determine *n*, the number of plats necessary to satisfy these conditions, substitute known values for symbols as follows:

General formula $\quad n = \left(\frac{\text{ratio } \sqrt{2}\ PE_s}{D}\right)^2$

By substitution $\quad n = \left(\frac{3.17 \times \sqrt{2} \times 11}{18}\right)^2$

Solving $\quad n = 7.56$

As there are many situations in which the application of the general formula should prove to be useful, certain constant values have been determined and a·e presented in the tables. In Table 1 the quotients resulting from dividing *ratio* $\sqrt{2}$ by *D* for varying values of the *ratio* and of *D* are displayed. The letter *F* is used as a symbol denoting any one of these values, as $F = \frac{\text{ratio } \sqrt{2}}{D}$.

The general formula becomes $n = (F.PE_s)^2$.

The several values of *n* have been calculated from the general formula holding *ratio*$\sqrt{2}$ constant at 4.5, the value necessary for odds of 30 : 1, and varying the magnitude of PE_s and D. These values appear in Table 2.

The sole purpose in presenting these tables is to enable the experimenter to obtain easily a rough approximation of the number of plats necessary in a proposed experiment. It is anticipated that the PE_s will have been determined through the analysis of data from previous experiments under similar conditions, for instance, it is fairly well established that the PE_s for oats and barley is approximately 5%.[4] It is not intended that the values in Tables 1 and 2 shall be used in any way in the analysis of data from completed experiments.

The application of the values of *F* in Table 1 to the solution of certain problems may be illustrated by the following type examples.

a. How many plats should be used to measure a difference of 10% with such a degree of precision as is represented by odds of approximately 30 : 1 if the PE_s of single row plats of wheat is 9.3% of the mean?

In Table 1, in column headed "10.0" at row "30 : 1", read the F value of .4483. Substituting known values for symbols in the formula $n = (F \cdot PE_s)^2$, the equation becomes $n = (.4483 \times 9.3)^2$, or 17.38.

Under the conditions set forth in the example 18 plats of each variety or treatment would be necessary to measure the difference.

[4] In New York, the PE_s for single-row cereal plats is 5%. This value has been determined from the deviations exhibited by thousands of units.

TABLE 1.—*The factor F calculated for certain values of the odds and the percentage difference to be measured.*

Odds	D/PE	Percentage difference to be measured										
		5.0	7.5	10.0	12.5	15.0	17.5	20.0	25.0	30.0	35.0	40.0
12:1	2.62	.7410	.4940	.3705	.2964	.2470	.2117	.1853	.1482	.1235	.1059	.0926
14:1	2.71	.7665	.5110	.3832	.3066	.2555	.2190	.1916	.1533	.1277	.1095	.0958
16:1	2.80	.7920	.5280	.3960	.3168	.2640	.2263	.1980	.1584	.1320	.1131	.0990
18:1	2.88	.8146	.5431	.4073	.3258	.2715	.2327	.2036	.1629	.1358	.1164	.1018
20:1	2.94	.8316	.5544	.4158	.3326	.2772	.2376	.2079	.1663	.1386	.1188	.1039
22:1	2.99	.8457	.5638	.4228	.3383	.2819	.2416	.2114	.1691	.1409	.1208	.1057
24:1	3.04	.8598	.5732	.4299	.3439	.2866	.2457	.2150	.1720	.1433	.1228	.1075
26:1	3.08	.8711	.5808	.4356	.3485	.2904	.2489	.2178	.1742	.1452	.1244	.1089
28:1	3.13	.8853	.5902	.4426	.3541	.2951	.2529	.2213	.1771	.1475	.1265	.1107
30:1	3.17	.8966	.5977	.4483	.3586	.2989	.2562	.2242	.1793	.1494	.1281	.1121
32:1	3.22	.9107	.6072	.4554	.3643	.3036	.2602	.2277	.1821	.1518	.1301	.1138
34:1	3.25	.9192	.6128	.4596	.3677	.3064	.2626	.2298	.1838	.1532	.1313	.1149
36:1	3.28	.9277	.6185	.4639	.3711	.3092	.2651	.2319	.1855	.1546	.1325	.1160
38:1	3.31	.9362	.6241	.4681	.3745	.3121	.2675	.2340	.1872	.1560	.1337	1170
40:1	3.34	.9447	.6298	.4723	.3779	.3149	.2699	.2361	.1889	.1574	.1350	.1181
42:1	3.37	.9532	.6354	.4766	.3813	.3177	.2723	.2383	.1906	.1589	.1362	.1191
44:1	3.40	.9617	.6411	.4808	.3847	.3206	.2748	.2404	.1923	.1603	.1374	.1202
46:1	3.41	.9645	.6430	.4822	.3858	.3215	.2756	.2411	.1929	.1607	.1378	.1206
48:1	3.42	.9673	.6449	.4837	.3869	.3224	.2764	.2418	.1937	.1612	.1382	.1209
50:1	3.45	.9758	.6505	.4879	.3903	.3253	.2788	.2439	.1952	.1626	.1394	.1219
52:1	3.48	.9843	.6562	.4921	.3937	.3281	.2812	.2461	.1969	.1640	.1406	.1230
54:1	3.50	.9899	.6600	.4950	.3960	.3300	.2828	.2475	.1980	.1650	.1414	.1237
56:1	3.51	.9928	.6618	.4964	.3971	.3309	.2836	.2482	.1986	.1655	.1418	.1241
58:1	3.53	.9984	.6656	.4992	.3994	.3328	.2853	.2496	.1997	.1664	.1426	.1248
60:1	3.56	1.0069	.6713	.5035	.4028	.3356	.2877	.2517	.2014	.1678	.1438	.1259
62:1	3.57	1.0098	.6732	.5049	.4039	.3366	.2885	.2524	.2019	.1683	.1442	.1262
64:1	3.59	1.0154	.6769	.5077	.4062	.3385	.2901	.2538	.2031	.1692	.1451	.1269
66:1	3.60	1.0182	.6788	.5091	.4073	.3394	.2909	.2546	.2036	.1697	.1455	.1273
68:1	3.62	1.0239	.6826	.5119	.4096	.3413	.2925	.2560	.2047	.1706	.1463	.1280
70:1	3.63	1.0267	.6845	.5134	.4107	.3422	.2933	.2567	.2053	.1711	.1467	.1283

TABLE 2.—*The number of units necessary to measure a given difference with such a degree of precision as is represented by odds of about 30:1.*

PEs in percentage of mean	Percentage difference to be measured															
	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	4	3	2	2	1	1	1	1	1	1	1	1	1	1	1	1
3	8	6	4	3	3	2	2	2	2	1	1	1	1	1	1	1
4	13	9	7	6	4	4	3	3	2	2	2	2	2	1	1	1
5	21	14	11	8	7	6	5	4	3	3	3	2	2	2	2	2
6	29	21	15	12	9	8	6	6	5	4	4	3	3	3	3	2
7	40	28	21	16	13	10	9	7	6	6	5	4	4	4	3	3
8	52	36	27	21	16	13	11	9	8	7	6	6	5	4	4	4
9	66	46	34	26	21	17	14	12	10	9	8	7	6	6	5	5
10	81	56	42	32	25	21	17	14	12	11	9	8	7	7	6	6
11	98	68	50	38	31	25	21	17	15	13	11	10	9	8	7	7
12	116	81	60	46	36	29	24	21	18	15	13	12	11	9	9	8
13	136	95	70	54	42	34	29	24	21	18	16	14	12	11	10	9
14	158	110	81	62	49	40	33	28	24	21	18	16	14	13	11	10
15	181	126	93	71	56	46	38	32	27	24	21	18	16	14	13	12
16	206	143	105	81	64	52	43	36	31	27	23	21	18	16	15	13
17	233	162	119	91	72	59	48	41	35	30	26	23	21	18	17	15
18	261	181	133	102	81	66	54	46	39	34	29	26	23	21	19	17
19	291	202	149	113	90	73	60	51	43	38	33	29	26	23	21	19
20	322	224	165	126	100	81	67	56	48	42	36	32	28	25	23	21
21	355	247	181	139	110	89	74	62	53	46	40	35	31	28	25	23
22	390	271	199	152	121	98	81	68	58	50	44	38	34	31	27	25
23	426	296	217	167	132	107	88	74	63	55	48	42	37	33	30	27
24	464	322	237	181	143	116	96	81	69	60	52	46	41	36	33	29
25	503	349	257	197	156	126	104	88	75	65	56	50	44	39	35	32
26	544	377	278	213	168	136	113	95	81	70	61	54	48	42	38	34
27	587	408	299	229	181	147	122	102	87	75	66	58	51	46	41	37
28	631	438	322	246	195	158	131	110	94	81	71	62	55	49	44	40
29	677	470	345	264	209	170	140	118	101	87	76	67	59	53	47	43
30	724	503	370	282	224	181	150	126	107	93	81	71	63	56	51	46

b. How small a difference may be measured statistically with odds of approximately 30 : 1 if five plats of each variety are planted and the PE_s is 9.3%?

Again substituting known values for symbols, the equation may be written $5 = (F \cdot 9.3)^2$ or $F^2 = \frac{5}{86.49}$ and $F = \sqrt{.0578}$, or .2404. In Table 1 in row "30 : 1" the F values nearest to .2404 are .2562 in column "17.5" and .2242 in column "20.0". Interpolation between these F values results in a difference-to-be-measured value of 18.73%.

It may be said that under the conditions as stated in this problem a difference of 18.7% is the smallest difference that can be measured with such a degree of precision as is represented by odds of approximately 30 : 1.

c. What degree of precision, as indicated by odds, may be attained when measuring a difference of 20% if there are five plats and the PE_s is 9.3%?

Again substituting known values for symbols, the equation is $5 = (F \cdot 9.3)^2$ and $F = .2404$. In column "20.0" the F value .2404 lies in row "44 : 1".

A difference of 20% under the conditions of this problem is significant, mathematically speaking, for the odds are approximately 44 : 1.

Certain uses of Table 2 may be illustrated by the following type examples.

a. How many units will be necessary to measure a difference of 12% with odds of approximately 30 : 1 if the PE_s is 10%?

In Table 2 at the intersection of column "12.0" and row "10.0" the number of 14 appears.

Fourteen plats would be necessary to satisfy the conditions as stated in this problem.

b. What is the smallest mathematically significant difference that may be measured in a small-grain yield trial if eight replications are used and the PE_s is 6%?

In Table 2 in row "6.0" the value of n (8) is found in column "10.0".

Therefore, 10% is the smallest difference that can be measured.

The prediction of future events from past experience is justifiable only when the past experiences taken together constitute an adequate sample of the infinite number of similar events which may occur in that universe. Fundamentally, the values in Table 1 and 2 represent an endeavor to project into the future certain knowledge acquired from present known facts. It is necessary, therefore, that these facts be well established.

The validity of the tabled values is quite dependent upon the significance of the probable error of a single determination (PE_s). If the PE_s has been determined from a relatively small population, it may or may not approximate the true value and the calculations from the tabled values will be in error to that extent. However, if the PE_s has been determined from large populations or if it is the mean of several PE_s derived from many similar experiments, then one may use Tables 1 and 2 with a reasonable degree of assurance as to the accuracy of the results.

These tables will also be quite exact for all values when n = 20 or more. However, if the experimenter expects to base his results on less than 20 plats, the tables cannot be expected to hold very accurately as they are based on the normal curve. As Student[5] has shown, the normal curve does not give exact results for small samples, but the exact dividing line (whether at n = 10 or n = 30) has not been satisfactorily determined.

[5]STUDENT. The probable error of a mean. Biometrika, 6: 1-25. 1908.

EFFECT OF DEPTH OF SUBMERGENCE ON THE CONTROL OF BARNYARD GRASS AND THE YIELD OF RICE GROWN IN POTS[1]

JENKIN W. JONES[2]

From 1912 to 1920 the rice crop of California was sown in the same manner as any other small grain and then irrigated and drained every 10 days or 2 weeks. About 30 days after the rice seedlings had emerged the land was irrigated and kept submerged continuously until drained for harvest. This method of irrigation was favorable for the growth, reproduction, and spread of the several varieties of barnyard grass (*Echinochloa crus-galli*). Large areas of the most productive rice lands became so foul with barnyard grasses that it was difficult to produce satisfactory rice crops.

Observations and trials, at first by rice growers and later by others, indicated that seeds of the common barnyard grasses do not germinate under water so well as do rice seeds, nor do the grass seedlings emerge through from 4 to 8 inches of water as well as do rice seedlings. As a result of these observations and trials a continuous submergence method of irrigation was adopted by which, under field conditions, common barnyard grasses are largely controlled.

Instead of the former practice with its alternate irrigating and draining, rice is now sown broadcast in the water or on a well-prepared seedbed, which is immediately submerged. The water is then held at an average depth of about 6 inches until the crop is ready to be drained for harvest. The rice germinates in and the seedlings emerge through the water. When rice is sown on a rough seedbed and is then submerged some of the seed is covered with a layer of soil from slacked clods. Such seed seldom germinates normally and often fails to produce seedlings that emerge to the surface of the water. To avoid this, most of the rice land is now submerged and the clods are slacked before the rice is sown

In using the continuous submergence method the depth of submergence must be considered, both in its effect on weed control and on the yield of rice.

Robertson (7),[3] Adams (1), Jones (5, 6), and Dunshee (4), working in California, report that the highest average yields of rice were obtained by continuous submergence of the land to a depth of 6 inches. At the Biggs Rice Field Station, Biggs, Calif., during an 8-year period, the average yield of rice on plats that were submerged 2, 4, 6, and 8 inches deep was 3,769, 3,839, 3,925, and 3, 834 pounds per acre, respectively.

In Louisiana, Chambliss and Jenkins (3) found that the highest average yield was obtained from plats continuously submerged 8

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the California Agricultural Experiment Station. Received for publication December 6, 1932.

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[3]Reference by number is to "Literature Cited," p. 583.

inches deep. The 2-inch depth of submergence, however, gave higher average yields than the 6-inch depth. In comparing the average yields from plats submerged 15, 30, 45, and 60 days after the rice emerged, they obtained a marked reduction in yield for each successively later date of submergence.

MATERIALS AND METHODS

Experiments on the effect of depth of submergence in pot cultures were begun in 1927. In these experiments galvanized cans 12½ inches in diameter and 21 inches deep were used, painted inside with Oronite roof paint. Fifty pounds of Stockton clay adobe surface soil were placed in each pot. The depths of submergence were 2, 4, 6, 8, and 10 inches. The soil was kept "mucky," or saturated, but not submerged in one set of pots. The pots were located in a coarse-screened inclosure that protected the plants from birds and other animals. All pots received the same cultural treatments, and each year all were submerged and the seed sown on the same date.

In the yield tests the Caloro variety was used, the seed for all pots coming from a single plant. For the weed-control experiments an identical set-up was used, except that barnyard grass instead of rice was sown.

Fallow soil was placed in the pots in 1927 and it was not changed during the 3-year period for which results are reported. In the yield tests shallow water, 2 inches deep, was held in all pots until the rice plants were large enough to withstand a greater depth of submergence. The depth of water was then gradually increased until the desired depths of submergence were attained. Thereafter, water was added daily or on alternate days to maintain the desired depths. Six rice plants were grown to maturity in each pot in all yield tests, unless otherwise stated. The shade cast by the sides of the pots somewhat retarded the early growth of the plants.

EFFECT OF DEPTH OF SUBMERGENCE ON THE CONTROL OF BARNYARD GRASS

Two 3-year studies were made on the effect of depth of submergence on the control of barnyard grasses. The first, from 1927 to 1929, dealt with the "white" barnyard grass, and the second, from 1928 to 1930, with the common barnyard grasses. The soil in the pots was submerged and the barnyard grass was sown in the water, with the exception of the pots in which the soil was kept in a mucky condition. In the first experiment 0.5 gram of white barnyard grass was sown in each pot; in the second experiment a mixture of common barnyard grass varieties was used.

The seed of white barnyard grass varieties is larger than that of the common varieties present in the rice area. White barnyard grass seedlings emerged each year through all depths of submergence. The depth of submergence, the date on which the seed was sown, and the date of emergence are shown in Table 1. Each increase in the depth of submergence, up to 8 inches, delayed the emergence of the seedlings, although there was little difference in the final stands. The

growth of the grass was better, however, in 2 and 6 inches of water than in 8 and 10 inches. The delayed emergence through the deeper water apparently had an injurious effect from which the plants did not fully recover. This also has been observed in fields where the plants are slow in emerging because of deep water. In 1929 the grass in three of the pots submerged 8 inches deep and in four of the pots submerged 10 inches failed to emerge. This was due to the collection of scum in these pots before the seedlings had emerged, the scum being precipitated by a light rain which carried the plants down with it.

TABLE 1.—*Depth of submergence, date on which seed was sown, and date of emergence of white barnyard grass sown in pots during the 3-year period from 1927 to 1929, inclusive, at Biggs, Calif.*

Depth of submergence, inches	Date sown			Date of emergence		
	1927	1928	1929	1927	1928	1929
2	May 9	May 16	May 1	May 21	May 26	May 10
4	May 9	May 16	May 1	May 24	May 29	May 14
6	May 9	May 16	May 1	May 28	June 1	May 17
8	May 9	May 16	May 1	June 3	June 5	May 28
10	May 9	May 16	May 1	June 6	June 5	May 28

In contrast to the results with white barnyard grass, control was obtained with common barnyard grass in each of the 3 years. Thick stands of grass were obtained in the mucky soil, whereas the stand decreased with increased depth of submergence in the pots continuously submerged 2, 4, 6, 8, and 10 inches deep, respectively.

The results obtained in 1929 were typical of all seasons. The seed sown May 1 on mucky soil emerged May 10 with an estimated stand of 100%; that submerged 2 inches emerged May 29 with an estimated stand of 10%; that submerged 4 inches emerged May 31 with an estimated stand of 5%; that submerged 6 inches emerged June 15 with an estimated stand of 1%; and from that submerged 8 and 10 inches no plants emerged. There was a marked reduction in the stands of grass as the depth of water increased from mucky to 6 inches.

As the depth of water increased, more time was required for the plants to emerge. Under favorable conditions, however, the plants were not killed at once by this delay, for in 1930 seedlings of common barnyard grass lived under clear water at high temperatures for 6 weeks. When organic matter was abundant, however, the decomposition of this material under warm water often resulted in the formation of floating scum on the water. Algae also may be abundant under such conditions. Even in shallow water, 2 to 4 inches deep, scum and algae often prevented the seedlings from emerging to the surface of the water.

Observations in commercial fields and in plat and pot experiments indicate that the control of barnyard grass by continuous submergence is the result of the interaction of several factors. Of these factors high water temperatures, shading of the seedlings by scum, algae, and rice plants, seed food supply, and reduced oxygen pressure in

warm water appear to be the most important. The elimination of the grass seedlings is a gradual process. Due to delayed emergence the seedlings often become coated with fine particles present in the water, which coating undoubtedly is injurious. They also are shaded by scum, algae, or rice plants, and at times by all three. The detrimental effect of this reduction in sunlight, combined with the limited supply of oxygen dissolved in warm water, appears to prevent normal photosynthetic activities, and death of the grass seedlings results. Rice, on the other hand, can germinate and emerge through the water at lower temperatures than can the common barnyard grasses. If sown early, the rice seedlings emerge through the water before temperatures are high enough to induce the formation of scum and much growth of algae. The slower growing common barnyard grass seedlings succumb. When rice is sown in water late in the spring and held continuously submerged, high-water temperatures with resultant low oxygen pres ure and the development of scum and algae may be just as serious for the rice as for the barnyard grass.

EFFECT OF DEPTH OF SUBMERGENCE ON GROWTH AND YIELD OF RICE

Each year there was a good deal of variation in height, in the number of culms, and in the yield of grain and straw within the replicated pots at each depth of submergence. There was a marked decrease in total height, number of culms, and grain and straw yields for all depths of submergence in 1928 as compared with 1927. A smaller number of culms and lower yields were obtained in 1929 than in 1928, but the decreases were less marked than for 1928. The variations in number of culms and yields of grain and straw for each depth of submergence were much smaller in 1928 and 1929 when the crop was grown on land cropped the previous year than they were in 1927 when the crop was grown on fallow land. The annual variation in yield for each depth of submergence was rather marked in most cases.

In Table 2 are given the mean height, number of culms, and yield of grain and straw for the 3-year period. The shortest and least productive plants were obtained from the soil kept in a mucky condition. The tallest plants were from the pots in which the soil was submerged 10 inches deep. The largest variation in height was for the plants grown in mucky soil. The largest number of culms was produced by the plants grown in soil submerged 6 inches deep. The largest variation in number of culms was from the plants grown in soil submerged 2 inches deep. The highest yields of grain were obtained from plants grown in soil submerged 4 and 6 inches deep. Higher yields were obtained by holding deep water, 8 and 10 inches, than by keeping the land in a mucky condition or submerging only 2 inches deep. The largest variations in yield of grain and straw were for plants grown in soil submerged 8 inches deep. The highest yield of straw was obtained from plants grown in soil submerged 6 inches deep.

The ratio of grain to straw varied from 1:1.33 for plants grown with a 4-inch depth of submergence to 1:2.04 for plants grown on mucky soil. Plants grown on soil kept mucky produced 36.8% as much

grain as those submerged 6 inches deep; and plants submerged 2, 8, and 10 inches produced 88.6, 97.9, and 96,3% respectively, whereas plants submerged 4 inches produced 3.1% more grain than those grown on soil submerged 6 inches deep.

TABLE 2.—*Mean height, number of culms, and yields of grain and straw for each depth of submergence with rice for the 3-year period, 1927–29, at Biggs, Calif.*

Depth of submergence	Mean height, inches	Mean number of culms	Mean grain yield, grams	Mean straw yield, grams
Mucky. . .	143.6±5.14	17.8±0.39	19.0±0.59	38.8±1.06
2-inch. . . .	186.1±2.44	25.6±0.60	45.7±0.82	62.2±1.62
4-inch. .	193.8±0.40	27.8±0.47	53.2±1.22	70.9±1.51
6-inch. . .	194.6±0.54	28.4±0.53	51.6±1.13	79.2±2.04
8-inch. . .	198.6±0.55	27.8±0.58	50.5±1.30	71.6±2.09
10-inch. .	199.9±0.55	26.8±0.44	49.7±0.55	74.3±1.52

The plants grown in soil kept mucky were from 7 to 10 days later in heading and from 11 to 14 days, or more, later in maturing than the plants submerged from 2 to 10 inches deep, respectively. All the submerged rice matured at the same time each year, whereas the plants grown in mucky soil were very irregular in maturing during each of the 3 years.

A film of algae often is found on the surface of submerged land. This film has been shown to be an important factor in the aeration of the roots of rice. Brizi (2) first pointed out in 1906 the significance of algae in the aeration of higher plants. He showed that algae from rice fields placed in cultures of rice containing carbon dioxide but no oxygen produced sufficient oxygen to aerate the roots and insure healthy growth. He concluded that the algae of rice fields greatly increased the amount of oxygen in the water and was the principal factor in the aeration of the roots. When a film of algae forms in the water before the emergence of grass seedlings, or rice seedlings, it has an entirely different effect.

SUMMARY

The locally known "white" barnyard grasses that have large seeds emerged each year through 2, 4, 6, 8, and 10 inches of water with similar stands. The time required for the seedlings to emerge varied with the depth of water. Deep water delayed emergence and reduced the growth of white barnyard grass plants, but did not control them.

The stands of common barnyard grasses on land continuously submerged 2, 4, 6, 8, and 10 inches deep, respectively, decreased with increased depths of submergence from 2 to 6 inches. Common barnyard grass seedlings did not emerge through 8 and 10 inches of water, although a few emerged through 6 inches of water.

The control of common barnyard grass by continuous submergence appears to be the result of the interaction of several factors. Of these factors, high water temperatures resulting in a low oxygen pressure and shade from scum, algae, and plant growth are the most important. Seedlings in shaded warm water are unable to remain alive and vigorous owing to disturbed photosynthetic activity.

Rice plants grown in soil kept in a "mucky" condition were shorter and produced fewer culms and much lower yields of grain and straw than plants grown on soil submerged 2, 4, 6, 8, and 10 inches deep, respectively.

The highest average yield of grain was obtained from plants grown in soil submerged 4 inches deep. The largest average number of culms and the highest average yield of straw were obtained from the plants grown in soil submerged 6 inches deep.

Plants grown on soil submerged 2 inches deep produced a smaller average number of culms and a lower average yield of grain and straw than plants grown in soil submerged 6, 8, and 10 inches deep, respectively.

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SOME FACTORS AFFECTING YIELD AND QUALITY OF CANNING CORN[1]

J. E. METZGER[2]

Extensive studies have been made of the chemical changes that take place in sweet corn during the ripening period with a view of establishing their effect upon the quality of the canned product. Appleman and associates (1, 2)[3] have studied the metabolism in green sweet corn at different storage temperatures and have determined the temperature efficiency for the ripening processes, a seasonal study. Culpepper and Magoon (3) studied the quality of sweet corn in relation to the degree of maturity of the ear and with reference to the varieties used by commercial canners. In a later report, they (4) give the temperature effects on the crop for several localities and for the entire period from planting to canning maturity. All of these researches have added to our knowledge of the character and quality of the ear when ready for the canner, and they have served as a useful index to the methods to be pursued at the time of harvesting the crop.

[1]Contribution from the Department of Agronomy, University of Maryland Experiment Station, College Park, Md. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication December 16, 1932.

[2]Professor of Agronomy and Assistant Director of the Experiment Station.

[3]Reference by number is to "Literature Cited," p. 587.

With the interest of the trade centered upon the quality of the canned product, it is essential that the grower be concerned with production factors that may affect both quality and yield. This report, therefore, deals with fertilizer analyses and rates of application as factors in the general problem of the quality of canning corn, together with their effect upon the acre value of a crop to the grower.

THE TEST PLATS

Eight fertilizer analyses[4] were used in the tests. These analyses varied from equal units of nitrogen and phosphorus (P_2O_5) to a ratio as wide as 1 to 6. The proportion of potash to phosphorus ranged from equal units to ratios of 1 to 2 and of 3 to 1. A 1-2-1 ratio was used on the check plats and in the rate of application series. The series provided sufficient ratios for a wide range of analyses. The analyses actually varied from 15 to 27 units. The rate of application of fertilizer was 400 pounds per acre except as noted. Row applications at planting time were used throughout the tests. A complete series of tests was conducted in each of three separate sweet corn producing areas and during a period covering three crop seasons.

EXPERIMENTAL RESULTS

Fertilizer tests on sweet corn (5) have been conducted for most part on the basis of the requirements of the crop from the standpoint of the market gardener rather than the canner. It is quite possible that the two interests may not be in harmony. In fact, there is much evidence in these results to indicate that they are not harmonious in every respect. An extended harvesting season in which the field is gone over several times is not objectionable to the market gardener, but the canner prefers one harvest only. Over-ripe ears and small short ears, the latter usually the result of multiple ear production, are waste in the canning factory. What the canner does desire is a high percentage of marketable ears uniform in maturity, size, and shape. The data given in Tables 1 and 2 are representative of the relations and trends shown by the results as a whole.

TABLE 1.—*Effect of nitrogen-phosphorus (P_2O_5) ratio on yield of sweet corn.*

Fertilizer ratio N to P_2O_5	Gross tons			Pounds of canning corn		
	College Park	Easton	West-minster	College Park	Easton	West-minster
1 : 1	1.98	2.29	1.78	713	1,082	1,016
1 : 2	2.09	2.09	1.93	856	914	1,021
1 : 4	2.21	2.33	2.20	945	959	1,219

DISCUSSION OF RESULTS

The experimental results secured in these tests indicate rather conclusively that a canning corn fertilizer should be rather high in

[4]In each analysis the nitrogen formula was sodium nitrate, 20%; ammonium sulfate, 60%; and urea, 20%. Where possible, 16% superphosphate was used. All of the potash was derived from the muriate.

TABLE 2.—*Effect of rate of application of a 1-2-1 ratio on gross yield, pounds of canning corn, and percentage of corn and mature ears.*

Fertilizer Application, pounds per acre	Yield per acre		Percentage of (total yield)	
	Gross tons	Canning corn, pounds	Canning corn by weight	Mature ears
200	1.88	873	24.0	41.8
400	1.90	914	23.9	43.6
600	2.12	933	23.0	43.5
800	2.09	940	24.2	44.7
1,000	2.05	876	21.8	39.4

phosphorus in proportion to nitrogen. Though conditions of drought, and high and prolonged summer temperatures caused some variations, the general trend was in the direction of the wider ratios. When total tonnage and the yield of cut corn are considered, the best analysis in the several series was a 3-12-6. The fields used in the Easton area (Coastal Plains) seemed to respond more favorably to nitrogen than those in either of the other locations. These soils are normally low in nitrogen and organic matter and in these tests indicated a greater need for this element than for phosphorus and potash. This relation holds for gross tonnage and canning corn yield but is less pronounced in the percentage of mature ears and cut corn. When all of the records, especially the seasonal influences, are taken into consideration, however, the general tendency in favor of high phosphorus obtains.

Throughout these tests the wide ratios (1 to 4) between nitrogen and phosphorus were reflected to a greater extent in the pounds of cut corn than in the total tonnage. These relations were especially striking for the College Park and Westminster plats. At the former location, for example, on leased land of low fertility the average increase of cut corn for the relatively high phosphorus plats was more than 20% greater than the gain made in total tonnage, and likewise on the Westminster plats there was a similar increase of nearly 10% in the cut corn yield. Where the ratio between nitrogen and phosphorus was as wide as 1 to 6, considerable damage to the crop was experienced from firing, especially in dry seasons. With a 1-2-1 ratio in the rate of application series, injuries from the large amounts were equally detrimental. With moderate though insufficient precipitation the relations were rather in favor of the higher nitrogen concentration, especially on the Coastal Plains. The indications are that the sweet corn crop responds best to moderate quantities of fertilizer with a medium ratio between nitrogen and phosphorus and that extremes in either the quantity used or the formula employed will depress yields rather than prove beneficial.

From the results obtained there was no significant evidence that relatively large quantities of potash (double the number of nitrogen and phophorus units) will influence favorably the yield of sweet corn. Slight increases were secured in the northern area, but in each of the others the differences would indicate further the importance of ample phosphorus rather than a need for large applications of potash. These

relations were determined by the use of the ratios 1-1-1; 1-1-2; 1-2-2 and 1-2-1. Although the yield data do not indicate important benefits from the use of potash, the percentage of mature ears was increased on the average by approximately 5% where the highest amounts of this material were used. There is evidence also that the larger amounts of potash had some influence on the growth of the vegetative parts, especially husks and leaves.

That growth and development in sweet corn may be influenced by the kind and amount of fertilizer used is shown best in the portion of the results pertaining to the percentage of cut corn and mature ears, the relative rapidity in which the crops matured, the toughness and density of the kernel, and the crude fiber content.

The percentage of cut corn was based upon the total weight or gross yield. This method tends to lower the results somewhat from those secured in the canning house but gives a more accurate picture of the response of the plants in the field. A change of 1% in the cutting yield is equivalent to approximately one-third of a case of No. 2 cans of corn per ton in a normal yield. The extreme variability in this factor was 7% (two cases of No. 2 cans) in favor of the higher phosphorus, but the average was only slightly over 2% As will be noted in Table 2, the rate of application seemed to have little influence on the percentage of cut corn and thus furnishes an answer to a question raised by many growers.

In these tests all ears that seemed to have matured to the canning stage were harvested, and the percentage was determined. At both College Park and Westminster substantial increases were secured in the number of mature ears for the higher phosphorus applications. In addition, many more rudimentary ears (not harvested) were formed on the main culm and on suckers of the high nitrogen plats than on the relatively high phosphorus areas. Field counts showed that the 1 to 1 nitrogen-phosphorus ratio plats produced nearly 100% more plants with more than one ear than were obtained from a 1 to 4 ratio. The relatively higher nitrogen concentration seemed to induce prolonged vegetative growth with the accompanied tendency for multiple ear production. On the other hand, an abundance of phosphorus hastened maturity with the result that fewer rudimentary ears were in evidence and a greater percentage of those started reached maturity. This tendency was most pronounced in 1929, a year in which both the temperature and precipitation were very favorable. Another factor that may cause variability in both the percentage of marketable ears obtained and the relative maturity rate is the character of the pollination. In the drought year of 1930 many plants produced all the parts of the ear but failed to develop kernels due to lack of pollination. This was an extreme year, but it represented a condition that obtains to a certain extent each year. It is a factor that can be controlled to a certain extent by the use of the most suitable planting date.

The puncture test as a measure of toughness was used in the experiments. Even with many hundreds of pressure measurements and a dispersion of more than 9% between the 1 to 1 and 1 to 4 nitrogen-phosphorus ratios, it cannot be certain that these pressure tests were

of any great significance. The number of variables is too numerous to make data of this kind reliable unless a greater number of factors can be determined than was possible in this study.

Crude fiber determinations were made on the mature kernels of representative plats. It was assumed that this, together with puncture test results, might serve as an index to the effect, if any, of the fertilizer on the toughness of the canned product. Some considerable differences developed which are hardly the results of variations in maturity dates and which doubtless must be ascribed to the character of the carbohydrate accumulation. By using the 1–1–1 ratio as a base, the percentage increases for several ratios were as follows: 3-4-2, 1.44; 1–2–1, 1.99; 1–6–2, 3.86; and 1–1–2, 7.51. It will be noted that in this nitrogen-phosphorus series there is a gradual increase in the crude fiber as the ratio becomes wider, with a large increase where the potash was doubled, but a decrease again if the proportion of nitrogen is raised.

SUMMARY

Eight fertilizer analyses together with five rates of application were tested in three areas in Maryland during three crop seasons. The indications are that the ratio of units of nitrogen to units of phosphorus should be about 1 to 4 and the ratio of phosphorus to potash units 2 to 1. Relatively higher amounts of nitrogen and potash result in delayed maturity, excessive husk growth, and multiple ear production.

A 1 to 2 ratio between nitrogen and phosphorus, even where large amounts of the complete fertilizer were used, was not sufficient to produce the maximum amount of cut corn per acre. It did increase the gross tonnage, however.

A high proportion of phosphorus in the mixture hastened maturity, shortened the interval during which the corn remained in its optimum canning condition, and developed a toughened pericarp a few days earlier than in plats containing relatively high nitrogen.

A fertilizer analysis like 3–12–6 produced best results from the standpoint of both canners and contract growers.

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SEASONAL PRODUCTION OF GRASSES AND LEGUMES AT BELTSVILLE, MARYLAND, IN 1931[1]

H. N. VINALL AND M. A. HEIN[2]

A generally recognized fact is that perennial grasses and legumes, even when supplied with adequate soil moisture and plant food, have in the temperate zone periods of active growth and other periods during the year when they are at least semi-dormant. The truly dormant period during the winter is of course due to low temperatures. In the summer, however, during July and August, Kentucky bluegrass and many other important pasture plants exhibit a reduced rate of growth which seriously affects their productiveness and consequent pasture value. This period of reduced growth occurs in most grasses coincident with or directly after that time of the year when these plants normally produce seed. Even though the grass is cut at frequent intervals preventing the actual formation of seed, there occurs a measurable retardation of the growth processes, an apparent physiological response of the plant to its environment, that is difficult to overcome.

The pasture experiments conducted cooperatively at Beltsville, Md., by the Bureaus of Plant Industry and Animal Industry have produced some results of interest in the above connection even though they have not continued long enough to be conclusive. These experiments on Sassafras silt loam soil were begun in the fall of 1928 when the plats under consideration, as well as the grazing paddocks used for a study of pasture management problems, were seeded.[3] Weather conditions were favorable at the time of seeding and the following spring, but thereafter rainfall was exceptionally deficient and these drought periods occurring each year interfered with a normal seasonal growth of the plants.

In this section of the United States, rainfall is certainly the largest factor in determining the distribution as well as the size of the crop. Only under irrigation could there be an adequate measure of other growth factors, such as temperature, day length, etc. The rainfall at Beltsville, Md., approached normal only in the spring and summer of 1931. This year is chosen, therefore, to illustrate the growth habits of the principal pasture plants. The actual as compared with the normal rainfall from January, 1929, to December, 1931, inclusive, is shown on the graph in Fig. 1. This illustrates admirably the very unusual conditions prevailing during this period and explains the lack of late summer growth as shown by the yields given in the tables which follow. From July, 1929, to and including February, 1931, there were only two months, October, 1929, and April, 1930, when

[1]Contribution from the Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication December 16, 1932.

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[3]The pasture mixture included the following quantities (pounds) of seed per acre: Kentucky bluegrass, 12; redtop, 3; timothy, 4; orchard grass, 4; meadow fescue, 4; Italian ryegrass, 8; perennial ryegrass, 4; red clover, 3; white clover, 2; alsike clover, 2; and lespedeza, 10.

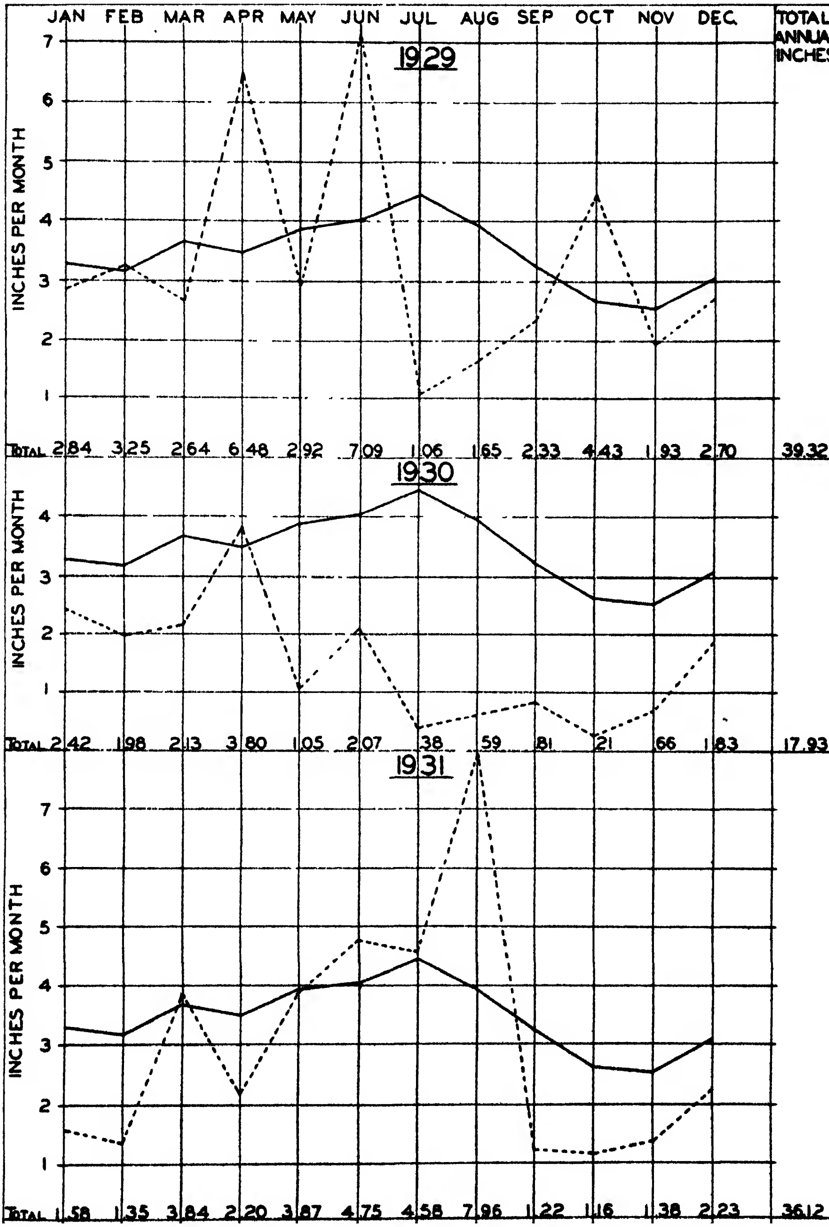

FIG. 1.—Rainfall at Beltsville, Md., by months for 1929, 1930, and 1931.

the rainfall equaled or exceeded the normal. During these 20 months the deficiency in rainfall was 36.1 inches, or 50.8%, of normal. The favorable rainfall in October, 1929, provided sufficient soil

TABLE 1.—*Acre yields in pounds of dry matter for a pasture mixture and certain pasture plants at Beltsville, Maryland, during 1931.*

Kind of plant	Lime 4 tons per acre in 1928; annual applications 24 pounds N, 64 pounds P_2O_5, and 50 pounds K_2O						Lime 4 tons per acre in 1928; no fertilizer applications					
	May 6–11	May 20–22	June 9–12	June 29–30	July 17–21	Aug. 27 to Sept. 2	May 6–11	May 20–22	June 9–12	June 29–30	July 17–21	Aug. 27 to Sept. 2
Pasture mixture	414	525	388	218	154	590	293	340	367	230	145	419
Kentucky bluegrass	560	550	302	219	318	425	214	215	168	111	133	192
German mixed bent	473	301	304	288	535	—	505	246	269	183	579	
Perennial ryegrass	—	283	213	217	126	192	—	293	143	276	100	329
Meadow fescue	—	—	218	380	214	374	—	—	192	255	201	409
Canada bluegrass	1,018	324	299	212	198	—	913	445	275	209	191	
Reed Canary grass	358	429	538	285	220	468	194	231	372	202	154	402
Brome grass	508	403	375	242	171	458	473	208	230	166	113	333
Orchard grass	317	530	331	179	171	409	281	195	259	205	178	371
Red fescue	518	539	255	—	177	448	536	418	173	—	166	448
Korean lespedeza	—	—	—	903	—	1,582	—	—	—	1,025	—	1,761
White clover*	—	—	856	197	288	390	—	—	655	115	273	263
Alsike clover	—	830	333	150	280	334	—	201	267	230	218	439
Red clover*	—	—	766	141	138	519	—	—	304	252	150	274
Alfalfa†	—	250	496	528	264	1,887	—	167	425	372	202	1,327

*These plats were all reseeded March 14, 1931.

†Reseeded March 14, 1931. The NPK plat was not representative and the yields from the NK plat were substituted therefor.

moisture for growth the following spring, and this was stimulated by the approximately average rainfall in April, 1930. When this supply of soil moisture was exhausted, growth ceased and no cuttings of any grass were made after July 10 of that year. The yields in 1931 of the pasture mixture and the most important grasses and legumes are given in Table 1.

Returning to a more direct discussion of the subject of this paper and considering only the yields of 1931, when the rainfall was favorable from March to August, inclusive, there appeared to be a rather uniform tendency for the pasture plants to make their most rapid growth in May despite a low April rainfall. This growth continued at a slightly decreased rate through June and a progressively slower rate through July and August notwithstanding a more than normal rainfall in July and excessive rains in August. Growth practically ceased by September 1, there being but little effective rainfall during the last 4 months of the year.

Observations indicate that active measurable growth of these pasture plants at Beltsville, Md., usually begins about April 1. The first cuttings in 1931 were made in the period May 6 to 11, which means that the production measured by this cutting was a measure of the growth from April 1 to May 6 or 11. Making the necessary adjustments for each of the 1931 cuttings in Table 1, we have an approximate measure of the production or growth for each month from April to August. These adjusted yields and the percentage each constitutes of the total annual yields during the summer of 1931 are given in Table 2.

Obviously the yields as allocated to the different months in Table 2 more accurately indicate the time when pasturage is available than does Table 1. In every case except those of Canada bluegrass, perennial ryegrass, and alfalfa the production was greatest in May. Canada bluegrass made 41% of its annual growth in April and showed a steadily decreasing rate of growth each succeeding month until August, when the growth was not sufficient to cut. Alfalfa showed a growth habit exactly the reverse of Canada bluegrass with 41% credited to August and only 3% for April. This behavior of alfalfa was due to the fact that it was reseeded March 14, 1931. An old stand would no doubt exhibit a stronger early growth.

Perennial ryegrass produced most in June, with 33% credited to that month and only 25% in May. Limited results in 1930 indicated a capacity in both alfalfa and perennial ryegrass for early growth. The results for the other plants in 1931 are in accordance with their behavior in other years and therefore appear reliable.

The behavior of the pasture mixture and of Kentucky bluegrass on unfertilized plats, in so far as the distribution of production was concerned, differed little from their behavior on fertilized plats. Fig. 2 clearly illustrates the seasonal production of a pasture mixture and Kentucky bluegrass on fertilized and unfertilized plats. Ordinarily one expects a larger early growth where fertilizers are applied.

The exposition of the monthly production of pastures at Beltsville is of particular interest to the livestock producers of Maryland and adjacent states east and west because it indicates so clearly the time

TABLE 2.—*Yields per acre of dry matter by months of a pasture mixture and the principal grasses and legumes at Beltsville, Maryland, 1931.*

Crop	April		May		June		July		August		Total
	Pounds	%	Pounds	%	Pounds	%	Pounds	%	Pounds	%	pounds
Pasture mixture	345	15	807	35	393	17	330	14	414	18	2,289
Pasture mixture*	244	14	591	33	395	22	270	15	294	16	1,794
Kentucky bluegrass	467	20	772	32	392	16	419	18	324	14	2,374
Kentucky bluegrass*	178	17	323	31	207	20	179	17	146	14	1,033
Canada bluegrass	745	36	732	36	376	18	198	10			2,051
Orchard grass	272	14	757	39	328	17	311	16	269	14	1,937
Brome grass	372	17	708	33	448	21	324	15	305	14	2,157
Reed Canary grass	307	13	749	33	554	24	376	16	312	14	2,298
German mixed bent	346	18	565	30	455	24	535	28			1,901
Perennial ryegrass	115	11	261	25	337	33	176	17	142	14	1,031
Red fescue	432	22	740	38	140	7	303	16	322	17	1,937
White clover			612	35	441	25	390	23	288	17	1,731
Alsike clover	337	17	643	33	333	17	391	20	223	12	1,927
Alfalfa†	100	3	362	11	636	18	934	27	1,393	41	3,425

*Yields from unfertilized plats. All other yields from plats with complete fertilizer, except where otherwise specified.
†Alfalfa yields from the NK plat (see Table 1).

of year when they may expect a peak in the production of their permanent pastures. Fig. 2 should be compared with Chart 1 in the article by Dr. J. B. Abbott of the Report of the Maryland Agricul-

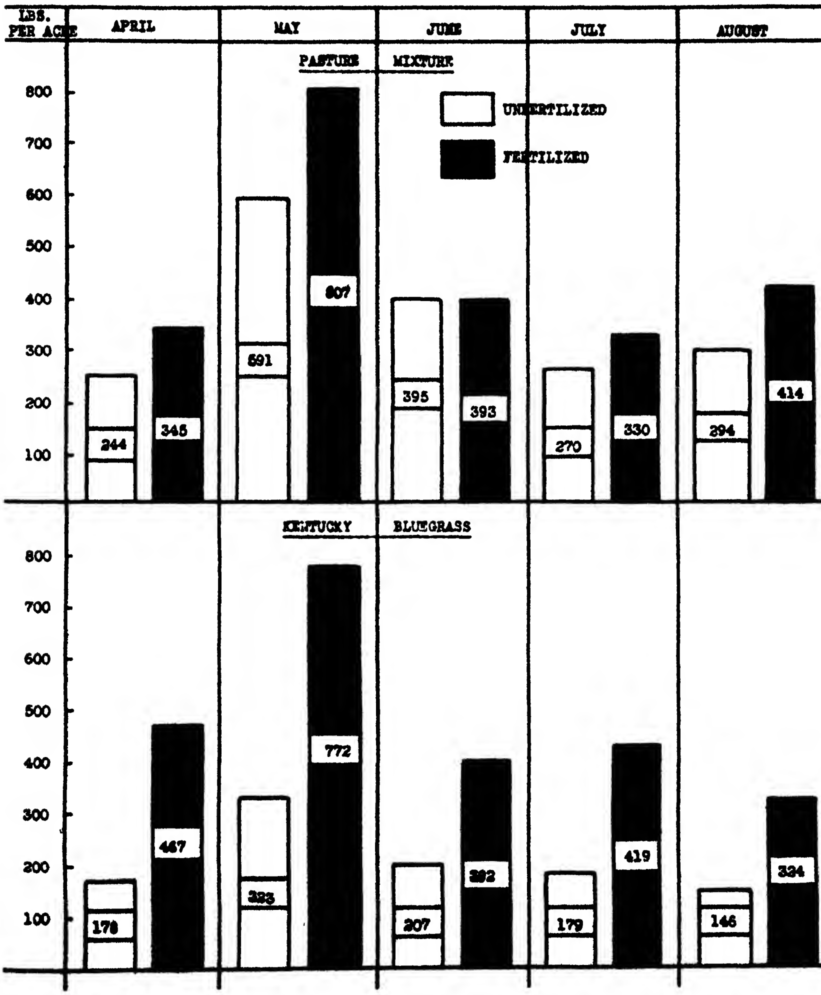

FIG. 2.—The yields per acre of dry matter by months of a pasture mixture and Kentucky bluegrass on unfertilized and fertilized plats at Beltsville, Md.

tural Society and Maryland Farm Bureau Federation (Vol. 15, page 273, 1930). This chart of Dr. Abbott's was evidently based on data obtained largely from pastures in New England, since it shows the largest production in June and the next highest in July. His comment on this chart, that, "it serves to point out one of the chief problems in improvement of pasturage; namely, *to produce more grazing when more grazing is urgently needed in May and in the latter part of the summer without producing a wasteful excess in June*," is obviously not

applicable to Maryland conditions where May and not June is the month of highest production in permanent pasture.

The accuracy of the graph in Fig. 2 is supported by the records of gains made by beef animals on the experimental pastures at Beltsville, Md. These paddocks were seeded to the same pasture mixture as that used in obtaining the yields shown in Fig. 2 and the seeding was done at approximately the same time in September, 1928. Table 3 shows the average daily gain of 13 steers for each of the four months May, June, July, and August in the four years 1929–1932, inclusive. Grazing began each year approximately on May 1 and continued until the animals were consistently losing weight in the fall. The gains or losses occurring after August are not presented in this table because only these months are included in Table 2. Four of the animals were grazed continuously on 8 acres; five continuously on 5 acres; and the four remaining were grazed alternately in 3-week intervals on two 2-acre paddocks. There is an exceptionally close agreement in the average daily gain for the different months and the yields of dry matter for the same months.

TABLE 3.—*Average daily gain of steers in pounds at Beltsville, Md., by months, 1929–32.*

Month	1929	1930	1931	1932	Average*
May	4.75	3.07	4.74	4.16	4.18
June	1.14	2.06	2.54	2.14	1.97
July	1.42	0.67	0.42	1.67	1.04
Aug	1.89	—0.26	0.98	1.06	0.92
Av. per season	2.30	1.38	2.17	2.26	2.03

*Under each month of each year is the average daily gain of 13 steers. The grand average, therefore, is the average daily gain of these 13 steers in 4 years for each of the 4 months.

SUMMARY

The data presented were obtained from plats on Sassafras silt loam at Beltsville, Md., seeded in September, 1928, to a pasture mixture and to each of the important pasture grasses and legumes. The plats devoted to the pasture mixture were in duplicate while all others were single plats. Cuttings were made with a lawn mower at intervals throughout the season whenever the growth was sufficient.

All the plats were limed and the yields in 1931 are shown for those receiving an application of complete fertili er and those unfertilized.

Rainfall was markedly deficient in 1929 and 1930 and seasonal production is therefore reported only for 1931.

Results indicate that the maximum growth of most standard pasture plants occurs in May when approximately 33% of the total annual yield of herbage is produced.

Rainfall in the late summer and fall was insufficient in each of the three seasons to provide an opportunity for a study of the ability of different grasses to renew their growth in the fall of the year.

PERSISTENCE OF GRASS AND LEGUME SPECIES UNDER GRAZING CONDITIONS[1]

M. A. Hein and H. N. Vinall[2]

To evolve a method whereby an accurate determination may be made of the plant population or the area occupied by each plant species is a difficult problem in pasture investigations. The Committee on Pasture Research of the Northeastern Section of the American Society of Agronomy sent out a questionnaire on the subject and the replies[3] received indicated a preference for the method of estimating the percentage of area occupied by each species, these estimates to be made in permanently marked quadrats or from a large number of small areas selected at random. The counting of individual plants appeared impracticable except during the year following the date of seeding before the stoloniferous plants, such as Kentucky bluegrass, developed a turf. In obtaining the data presented here, the plant count method was used in 1929, but after that estimates were made of the percentage of area occupied by each species.

These experiments are located on the farms of the Bureau of Animal Industry and the Bureau of Dairy Industry at Beltsville, Md., where the Bureau of Plant Industry is cooperating with these Bureaus in pasture research. The soils belong to the Sassafras series, are low in organic matter content, and although only slightly acid, they respond to limestone. Prior to the inauguration of the pasture experiments in the fall of 1928, the land had been under general farm cultivation for a number of years.

The experimental pastures were seeded as one field and then divided into their respective paddocks. In making up the mixture, seeds of all pasture plants considered suitable for this region were included, making a complex and heavy seeding. The seeds were mixed and applied at the following rates per acre: Kentucky bluegrass, 12 pounds; redtop, 3 pounds; timothy, 4 pounds; orchard grass, 4 pounds; meadow fescue, 4 pounds; Italian ryegrass, 8 pounds; perennial ryegrass, 4 pounds; red clover, 3 pounds; alsike clover, 2 pounds; white clover, 2 pounds; Korean lespedeza, 4 pounds; and common lespedeza, 10 pounds. This seeding was done in September, 1928, except where otherwise noted.

On the pasture management experiment the seeding emerged to a good stand and made a good fall growth, but the Hohenheim pastures made a slow fall and spring growth, due to late seedbed preparation. This land was not plowed and worked down until a week previous to seeding, while the pasture management land was plowed 6 weeks before seeding and disked twice during that period to kill weed growth. This early preparation made a firm seedbed, ideal for quick and uniform germination, and reduced the loss by winter killing or "heaving."

[1]Contribution from the Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication December 16, 1932.

[2]Assistant Agronomist and Senior Agronomist, respectively.

[3]Unpublished data.

The continuously grazed pastures included as a check for the Hohenheim system were not seeded until the spring of 1929, as the land was not available in time for fall seeding. These pastures, seeded in April 1929, made an excellent growth and by June 1 were as far advanced as the Hohenheim pastures which suffered from "heaving" during the winter.

Weather conditions have been abnormal since the spring of 1929. In 1930, this region suffered from the most severe drouth on record. From April to October of that year the total rainfall was 8.70 inches, which is 13.26 inches below normal. In 1931, the rainfall was sufficient for crop development but not enough for reserve moisture. This lack of reserve moisture became noticeable early in 1932 when rainfall was again less than normal.[4]

In the spring of 1929 permanently marked quadrats of 9 square feet were marked off in each pasture and remained subject to grazing. Each spring and fall plant population records were made on these areas except in the fall of 1930 at which time the growth was eaten too close for positive identification of the plants.

In 1929, the records were taken by identifying and counting the individual plants. Since that time it has been impossible to determine the number of individual plants without disturbing the growth of turf-forming pasture plants. For this reason beginning in 1930 estimates were made each spring and fall of the relative area occupied by the different plant species in addition to the bare ground.

The stand of lespedeza is not included in this data because at the time of making the spring plant population counts many of the plants are in the seedling stage and some seeds have not germinated. The value of lespedeza is not disregarded, however, as an inspection is made of the pastures and the amount of grazing furnished by lespedeza is estimated at the time when its growth reveals the optimum contribution of this species.

In counting the number of clover plants in 1929 no attempt was made to identify the three species of clover that had been seeded. After that year white Dutch clover was the only species present in the quadrats. In fact, red clover and Alsike clover had disappeared almost completely from the pastures at the end of the first year.

Some explanation should be made regarding the presence of Canada bluegrass which was not included in the seed mixture. There are two reasons, at least, for its presence. A few plants were noted in the fields before they were plowed in preparation for seeding and the purity test showed a small amount of Canada bluegrass in the redtop and orchard grass seed.

As shown by the number of plants per square foot in Tables 1 and 2, it is evident that an excellent stand was obtained of all species in the seed mixture. The quadrats were quite representative of the various pastures at that time, but the ryegrasses, because of their rapid growth, made up over 50% of the available forage until midsummer of 1929. Since then the quadrats have for the most part continued

[4]For rainfall records see Vinall, H. N., and Hein, M. A. Seasonal production of grasses and legumes at Beltsville, Maryland, in 1931. Jour. Amer. Soc. Agron., 25: 588-594. 1933.

typical of the area under the particular grazing system they represented.

PASTURE MANAGEMENT EXPERIMENT

These pastures received an initial fertilizer application of 400 pounds of 16% superphosphate and 100 pounds of sulfate of potash per acre in the fall of 1928. In the spring of 1931 another fertilizer application of 100 pounds of nitrate of soda, 400 pounds of 16% superphosphate, and 100 pounds of muriate of potash per acre was made to aid the grass in recovering from the drouth of 1930. Limestone was applied at rates of 1 or 2 tons per acre, according to the need as indicated by detailed acidity tests in the field.

This experiment is a comparison of different rates of grazing with beef steers, the animals receiving no supplemental feed while on pasture. It includes continuous light grazing (2 acres per steer); continuous heavy grazing (1 acre per steer); and alternate heavy grazing (1 acre per steer), the two divisions being grazed in 3-week intervals. According to the system proposed by Vinall and Semple[5] this would be equivalent to 2⅔ acres per animal unit under light grazing and 1 1/3 acres per animal unit under heavy continuous and heavy alternate grazing. During the spring none of these rates of grazing utilized all the grass and about the middle of June the excess growth was clipped to a height of 4 inches. This excess growth was removed as hay when the growth warranted, which has been the case under light grazing each year. No hay was removed from any of the heavy grazed pastures except in 1929. Grazing began the first of May each year and continued until the middle of October when there was sufficient forage for the animals. In 1930, it was necessary to end the grazing season on August 21 and in 1932 on September 21.

In each of these years, however, the light-grazed pasture had an abundance of feed at the end of the grazing season and the steers were continuing to gain, but the vegetation in the heavy-grazed pastures was eaten to the ground and the animals were consistently losing weight.

The data in Table 1 indicate that the different rates of grazing have had a definite effect on the plant population. Under light grazing the area of bare ground did not increase after the drouth of 1930 as it did under heavy grazing. After the application of fertilizer and with better seasonal conditions during 1931, the heavily grazed pastures recovered and by the spring of 1932 the bare ground was practically the same in all pastures.

Under light grazing Kentucky bluegrass decreased from 13% in 1930 to less than 6% in 1932, while Canada bluegrass increased from 22.2% to almost 42% in the same time. Timothy also increased from 14% to 24% under this method of grazing, while orchard grass maintained a stand of about 8% except in 1931 when it dropped to less than 4%. All the other grasses and legumes that were seeded and appeared in the plant counts made in 1929 have disappeared from this quadrat.

[5]Vinall, H. N., and Semple, A. T. Unit days of grazing. Jour. Amer. Soc. Agron., 24:836–837. 1932.

TABLE 1.—*Initial stands and resulting percentages of certain grasses and legumes under different methods of grazing at Beltsville, Md.*

	Light continuous grazing				Heavy continuous grazing				Heavy alternate grazing			
	Initial stand, 1929*	Resulting percentages			Initial stand, 1929*	Resulting percentages			Initial stand, 1929*	Resulting percentages		
		1930	1931	1932		1930	1931	1932		1930	1931	1932
Bare ground	–	31.1	19.4	20.0	–	25.6	30.0	14.4	-	25.8	46.0	22.0
Kentucky bluegrass	3	13.0	1.7	5.7	4	22.8	20.9	23.1	6	17.6	15.4	36.0
Canada bluegrass	1	22.2	49.4	41.9	0	10.1	26.3	18.2	0	0.0	1.5	7.3
Timothy	5	14.4	23.9	24.4	6	17.2	14.6	3.2	5	20.0	32.0	22.8
Redtop	4	4.4	0.0	0.0	2	7.7	0.0	0.6	3	14.2	3.8	3.9
Orchard grass	3	9.4	3.7	8.0	2	2.3	1.6	0.2	2	3.9	0.6	2.2
Italian ryegrass	4	0.0	0.0	0.0	3	1.1	0.0	0.0	6	0.6	0.0	0.0
Perennial ryegrass	4	4.0	1.9	0.0	4	9.0	2.7	0.7	3	7.4	0.3	1.4
Meadow fescue	3	0.0	0.0	0.0	3	3.3	0.0	0.0	3	4.9	0.0	0.0
Clover	5	1.2	0.0	0.0	2	0.5	T†	38.2	7	3.5	T†	4.0
Weeds	2	0.3	0.0	0.0	2	0.4	3.9	1.4	6	2.1	0.4	0.4

*Number of plants per square foot.
†Trace.

Under heavy continuous grazing Kentucky bluegrass maintained approximately the same stand, *viz.*, 21% to 23%, for the 3 years, 1930–32, while the stand of Canada bluegrass varied as follows: 10% in 1930, 26% in 1931, and 18% in 1932. The percentage of timothy decreased from 17% in 1930 to 3% in 1932, while redtop decreased from 7.7% to less than 1%. Orchard grass and perennial ryegrass have practically disappeared. Italian ryegrass and meadow fescue completely disappeared from all the pastures. The most outstanding change in percentage of ground cover was that of clover which, under this method of grazing, increased from less than 1% in 1930 to over 38% in 1932. This increase is not shown in the table, however, as it was made during the summer of 1931, after the spring estimate had been made.

The plant population data from the heavy alternate grazing is an average of estimates from two quadrats, one located in each pasture. Under these grazing conditions Kentucky bluegrass increased from 17.4% in 1930 to 36% in 1932. Canada bluegrass, which was not represented in the 1930 estimates, occupied over 7% of the area in 1932. Timothy varied from 20% in 1930 to 32% in 1931 and about 23% in 1932. Redtop decreased from 14.2% to less than 4% during this period. Orchard grass and perennial ryegrass were still present in small amounts, while Italian ryegrass and meadow fescue had disappeared. Clover made up 3.5% of the stand in 1930, was not present in appreciable amount in 1931, but by 1932 constituted 4% of the mixture.

Before concluding the discussion of these data, a comparison should be made of the stand of some of the more important pasture plants in the quadrats. Kentucky bluegrass and white clover have both increased under heavy grazing and decreased under light grazing. Under light grazing Canada bluegrass has practically doubled its relative percentage of ground cover and now constitutes over 40% of the stand, but when heavily grazed it makes up less than 20% of the stand and shows an actual decrease of 8% from 1931 to 1932. Timothy has maintained a stand of over 20% under light continuous and heavy alternate grazing but has decreased to approximately 3% under heavy continuous grazing. Orchard grass has maintained its relative stand best under light grazing. White Dutch clover increased to almost 40% under heavy continuous grazing, completely disappeared under light grazing, and constituted only 4% of the ground cover under alternate grazing. Weeds have not appeared in appreciable numbers in any of the quadrats.

HOHENHEIM SYSTEM AND CHECKS

The purpose of this experiment is to compare the Hohenheim, or fertilized-rotation system of grazing, with the usual method of continuous grazing, one continuous grazed pasture being fertilized the same as the Hohenheim system and the other unfertilized. Dairy cows and heifers were used for grazing. In 1929, the grass was clipped in the spring and the animals were not turned on the pasture until June 1 and were removed October 14. In 1930, grazing began April

15, but the drouth made it necessary to remove the animals Sept. 22. In 1931, the dates for the beginning and ending of the grazing period were April 28 and October 11, respectively. In 1932, grazing began on April 16 and ended October 18.

The fertilized pastures received an annual application of 400 pounds of 16% superphosphate and 100 pounds of muriate of potash per acre in late winter or early spring. Nitrogen was applied at the rate of 100 pounds of nitrate of soda or 75 pounds of ammonium sulfate per acre at each application. The maximum total for any one season was 400 pounds of nitrate or 300 pounds of sulfate per acre. On the Hohenheim system the first application was made in the spring about 6 weeks before grazing began, the following applications being made after every second rotation of the cattle. In the Hohenheim system quadrats were located in two of the paddocks and the data in Table 2 are an average of these quadrats. There is one quadrat in each of the continuously grazed pastures.

The plant population in these quadrats was unlike that of the pasture management experiment. Under the Hohenheim system of treatment, Kentucky bluegrass increased from over 24% in 1930 to almost 70% in 1932, while Canada bluegrass never exceeded 7.5% during that time. Timothy decreased from 17.4% to 1% and redtop from 10.2% to 1%. Orchard grass maintained a stand of a little more than 6% except in 1931 when only 3.1% was present. Italian ryegrass made up over 3% of the stand in 1932, but this was thought to be from natural reseeding rather than from the original seeding in 1928. Perennial ryegrass, meadow fescue, and clover had practically disappeared in 1932, although they made up 13.1%, 3.1%, and 10.1% respectively, of the 1930 stand.

The quadrat located on the continuously grazed fertilized pasture contained over 33% Kentucky bluegrass in 1930, which decreased to 25.6% in 1931 but increased to almost 43% in 1932. During this time Canada bluegrass did not appear until 1932, at which time almost 8% was present. Timothy decreased under the continuous grazing from 7.1% in 1930 to less than 1% in 1932. Redtop and orchard grass increased from 8.3% and 7.8% to 20% and 16.7%, respectively. Perennial ryegrass made up 12.1% and 16.7% of the ground cover in 1930 and 1931, respectively, but decreased to less than 3% in 1932. Meadow fescue disappeared completely, while clover, which had never been prominent since 1929, was less than 1% in 1932.

Under continuous grazing without fertilizer the change in plant population has been much the same as on the fertilized pasture except that the quadrat on the first mentioned area has 16.1% of bare ground while on the area fertilized there is only 7.8% bare ground. Kentucky bluegrass, redtop, and orchard grass make up over 80% of the pasture plants present in 1932. Timothy, Italian ryegrass, meadow fescue, and clover have disappeared entirely while perennial ryegrass, which was 12% of the stand in 1930, now makes up less than 2%. Weeds have not been present in any of the quadrats in this experiment to any appreciable degree.

From a comparison of the relative area occupied by the different species in these various quadrats, it may be seen that Kentucky

TABLE 2.—*Initial stands and resulting percentages of certain grasses and legumes in the Hohenheim and check pastures at Beltsville, Md.*

	Hohenheim fertilized rotation system				Continuous grazed, fertilized				Continuous grazed, not fertilized			
	Initial stands, 1929*	Resulting percentages			Initial stands, 1929*	Resulting percentages			Initial stands, 1929*	Resulting percentages		
		1930	1931	1932		1930	1931	1932		1931	1930	1932
Bare ground	—	11.5	39.7	9.2	—	21.7	28.3	7.8	—	15.5	23.7	16.1
Kentucky bluegrass	4	24.2	38.7	69.9	3	33.3	25.6	42.8	3	39.3	18.3	46.1
Canada bluegrass	0	0.0	2.0	7.5	0	0.0	0.0	7.8	0	0.0	0.0	1.1
Timothy	7	17.4	12.5	1.0	1	7.1	6.9	0.6	3	3.9	5.2	0.0
Redtop	2	10.2	0.7	1.0	1	8.3	7.2	20.0	1	14.0	11.1	15.6
Orchard grass	2	6.1	3.1	6.7	5	7.8	8.3	16.7	6	7.2	11.7	19.4
Italian ryegrass	3	2.8	0.0	3.3	4	3.3	0.0	0.2	4	5.6	1.1	0.0
Perennial ryegrass	3	13.1	2.3	0.2	3	12.1	16.7	2.8	4	12.8	12.8	1.7
Meadow fescue	2	3.1	1.0	0.0	2	5.6	7.0	0.0	3	1.7	16.1	0.0
Clover	6	10.1	0.0	0.3	5	0.7	0.0	0.6	5	T†	0.0	0.0
Weeds	6	1.5	0.0	0.9	6	0.1	0.0	0.7	5	T†	0.0	0.0

*Number of plants per square foot.
†Trace.

bluegrass makes up a much larger percentage of the stand in the Hohenheim pastures than in either of the continuously grazed areas although these latter pastures contain a high percentage of this excellent pasture grass. An explanation for this is that these continuously grazed fields were in an excellent state of fertility when the experiment was started, which should be considered in a discussion of the data. Timothy has been crowded out of all quadrats. Redtop and orchard grass have been able to maintain a much better stand under continuous grazing, either fertilized or unfertilized, as compared with the rotation grazing. The absence of clover on the fertilized fields can best be explained by the fact that they received large amounts of nitrogen fertilizers in continuous applications, causing a heavy grass growth thus smothering out the clover. It is difficult, however, to arrive at any real reason for its absence on the unfertilized pasture unless the heavy grass growth that was obtained the first year crowded out the clover and it has not recovered. This pasture did not have a heavy stand of either common or Korean lespedeza in 1930 and 1931, but it was estimated that during August, September, and most of October of 1932, lespedeza made up almost 35% of the forage. It may be that the heavy stand of this legume is taking the place of the clover under these conditions.

In conlusion, it may be well to point out that these data are not presented with the idea that they give a botanical analysis representing exactly the pastures in which the various quadrats are located. The areas are too small to be truly representative. It can be stated, however, that a comparison of these results with notes taken each year of the general plant population of the pastures shows an interesting and significant correlation.

THE EFFECT OF LIME AND OF CERTAIN FERTILIZER CONSTITUENTS ON THE YIELD AND COMPOSITION OF THE HERBAGE FROM PASTURE PLATS AT BELTSVILLE, MARYLAND[1]

H. L. Wilkins and H. N. Vinall[2]

The field in which this experiment is located had previously one application of manure, but the rate and date are not known. In the spring of 1928 nitrate of soda was applied to a corn crop at the rate of approximately 100 pounds per acre. The area used for the experiment is divided into 25 plats 12 feet wide and 96 feet long, exclusive of the end borders. The arrangement and treatment of the plats is shown in Fig. 1. Before the plats were seeded all but 1, 13, and 25 were treated with ground limestone at the rate of 4 tons per acre. The fertilizers are applied annually at the following rates per acre: N, 24 pounds; P, 64 pounds of P_2O_5; and K, 50 pounds of K_2O. These amounts are applied in the spring as nitrate of soda, superphosphate, and muriate of potash, except that the first application was made shortly before the grasses were seeded in the fall of 1928 and differed from the subsequent ones in that sulfate of potash was used instead of the chloride and that the nitrate of soda was applied half in the fall of 1928 and half in the sprng of 1929. No other fertilizers were put on in 1929 and the spring treatments began in 1930. The fertilizer treatments extend across all of the plats in such a way as to divide them into eight equal sub-plats, each 12 feet wide and 17.75 feet long. A border 15 inches wide (one-half of the lawn mower width) is cut off each side and there remains about 1/300th of an acre from which the samples are harvested. The grasses were sown in October, 1928, and the legumes the following spring.

The samples were obtained by mowing the plats with a lawn mower as often as the growth reached a height of about 3 inches. From the harvest thus obtained two samples of about 2 pounds each were taken. If there was not enough material for two samples, the entire harvest was used for the sample. All of the samples were dried in a ventilated room which was kept at 35° to 45°C. This usually required about 4 days. The dried samples were then stored in a rodent-proof and well-ventilated loft. One sample was used for the determination of total moisture. The sample for the chemical analysis was ground through a 1-mm screen in a Wiley laboratory mill and mixed in a 5-pound MacLellan batch mixer. Two pint fruit jars (glass topped) were filled with the mixed sample. One jar served as an emergency reserve supply. As far as possible, all of the portions of the sample for use in making the analyses were weighed out at one sitting and either placed in the appropriate vessels or stored in

[1]Joint contribution from the Bureau of Plant Industry and Bureau of Animal Industry U. S. Dept. of Agriculture, Washington, D. C. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication December 16, 1932.

[2]Assistant Chemist and Senior Agronomist, respectively.

1-ounce ointment tins. The methods of analysis were mostly slight modifications of those of the Association of Official Agricultural Chemists. Since the real effect of fertilizer treatments could not be expected the first year (1929) and since many of the samples were destroyed by fire, this discussion is confined to crops harvested in 1930 and 1931.

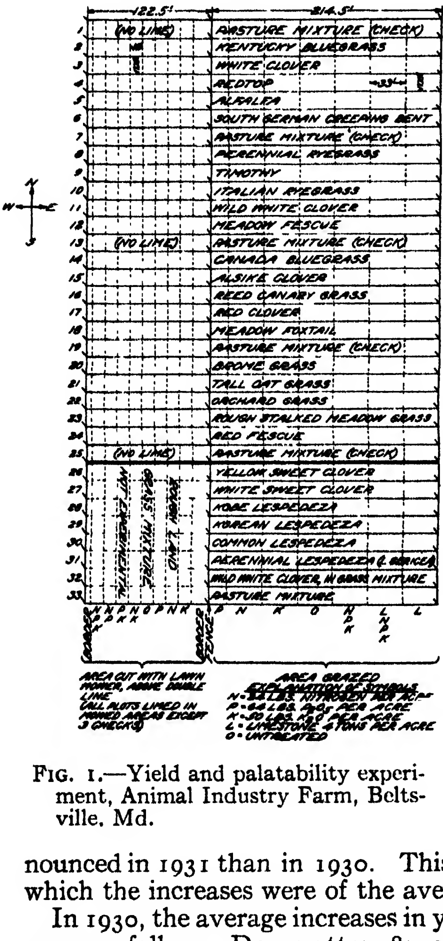

FIG. 1.—Yield and palatability experiment, Animal Industry Farm, Beltsville, Md.

EFFECT OF LIME ON THE YIELDS OF DRY MATTER AND CERTAIN NUTRIENTS

Generally speaking, the use of lime resulted in an improvement in the yield and chemical composition of the herbage from the pasture mixture plats. The average increases in the seasonal yield of dry matter and of certain nutrients, such as crude protein, calcium, and phosphorus, due to the application of lime, are shown in Table 1. This table also shows the effect of lime on the percentage of these nutrients in the dry matter of the herbage. These percentage figures indicate that the increased yield of these nutrients is not altogether due to the increase in the yield of dry matter. The effect of lime in increasing the yields of dry matter, protein, calcium, and phosphorus appeared to be much more pronounced in 1931 than in 1930. This was true also of the percentages which the increases were of the average yields of the unlimed plats.

In 1930, the average increases in yield due to the application of lime were as follows: Dry matter, 87 pounds per acre or 9.53%; crude protein, 19.5 pounds per acre or 14.66%; calcium, 1.42 pounds per acre or 34.61%; and phosphorus, 0.34 pounds per acre or 11.23%.

In 1931, the corresponding increases were: Dry matter, 347 pounds per acre or 20.69%; crude protein, 63.6 pounds per acre or 22.50%; calcium, 3.75 pounds per acre or 53.99%; and phosphorus, 2.39 pounds per acre or 37.58%.

In both years the percentage of increase in the yield of calcium is greater than that of dry matter, crude protein, or phosphorus.

The relative effectiveness of the several fertilizer treatments on the basis of yields *when lime was not applied* is indicated by the frequency with which a given fertilizer treatment ranks high or low in the

average season yield of the separate constituents under consideration. If these rankings are scored for the 2 years according to a system in which the best possible score is 8 and the poorest 64, then nitrogen alone stands first and the others follow with the scores indicated: N, 14; NK, 19; K, 25; P, 34; NPK 35; NP, 45; O, 49 (check); and PK, 62. However, *when lime is applied* in addition to the fertilizers, then the relative effectiveness of the treatments is changed and a combination of nitrogen and potash with lime stands first with the other treatments following in this order: LNK, 8.5; LNPK, 26; LNP, 28; LN, 33; LP, 38.5; LPK, 43; L, 47 (check); and LK, 64.

In the preceding paragraph the effectiveness of the different fertilizer treatments were ranked on the basis of the frequency with which the yields from a given treatment exceeded the yields from other treatments without regard to the extent of this excess in yields. Under this method a small difference has as much weight as a large one. If the effect of lime applications in increasing the yields due to different fertilizers is measured by the size of the respective increases in the yields on the limed over the unlimed plats, as shown in Table 1, then the frequency ranking and scores of the different fertilizer treatments would be as follows: NP, 18; PK, 21; NPK, 25; NK, 25; O (check), 38; N, 57; and K, 62. Under this method of measuring the effect of lime it will be noted that the effect was greater on all the combinations of fertilizer elements and even on the check plat than on any of the applications of single elements. It is obvious also that applications of N and K were benefited less often by lime than were any of the other treatments.

Where the size of the increase due to lime was considered, and contrary to the general trend of the data, the N and K treatments constitute all the cases where lime applications did not increase the yields. In both years, except for the average yield of phosphorus in 1931, applications of potash plus lime have produced less than potash alone. In 1930, nitrogen plus lime produced less of each constituent than did nitrogen alone, with the single exception of calcium. In 1931, however, the use of lime with nitrogen gave increased yields (over nitrogen alone) of all constituents. Additions of lime would of course be expected to increase the calcium in the herbage. Where there is an increase in yields of the LN plats over the N plats, it is small and is in no case as large as the seasonal average increase for the constituents as a whole. In considering the above rankings it must be remembered that the scores are an expression of the frequency and not the degree of superiority.

EFFECT OF LIME ON COMPOSITION OF HERBAGE

Applications of lime to the plats have, in most cases, increased the percentage of crude protein, calcium, and phosphorus in the herbage, but an examination of Table 1 shows that none of these average percentage increases were large. Even on a relative basis, only the increases for calcium and phosphorus amount to more than 4.5% of the average percentage of the respective constituent in the herbage from the unlimed plat. In 1930, there was an average increase of

TABLE 1.—*Effect of lime on the yields of dry matter, crude protein, calcium, and phosphorus in a pasture mixture under different fertilizer treatments at Beltsville, Md.*

Fertilizer treatment	1930						1931					
	Average yield, pounds per acre			Composition, average %			Average yield, pounds per acre			Composition, average %		
	Limed	Not limed	In-crease	Limed	Not limed	In-crease	Limed	Not limed	In-crease	Limed	Not limed	In-crease
					Dry Matter							
NPK	1,045	913	132	34.2	32.9	1.3	2,286	1,576	710	24.8	24.5	0.3
NP	1,058	742	316	31.5	32.1	—0.6	2,176	1,552	624	25.8	25.6	0.2
PK	891	751	140	35.2	34.2	1.0	1,939	1,343	596	24.9	26.2	—1.3
NK	1,197	1,090	107	33.2	32.2	1.0	2,536	1,981	559	24.3	24.3	0.0
O	943	928	15	34.2	34.0	0.2	1,792	1,437	355	24.6	25.3	—0.7
P	901	783	118	33.2	33.5	—0.3	1,962	1,708	254	25.2	23.5	1.7
N	1,148	1,225	—77	32.9	31.2	1.7	2,002	1,906	96	25.2	24.0	1.2
K	803	859	—56	34.5	33.0	1.5	1,462	1,874	—412	25.3	23.0	2.3
Av.	998	911	87	33.6	32.9	0.7	2,019	1,672	347.0	25.0	24.5	0.5
Av. percentage increase*			9.53	—	—	—	—	—	20.69	—	—	—
					Crude Protein (N x 6.25)							
NPK	163.0	146.4	16.6	15.39	15.03	0.36	398.2	278.2	120.0	18.22	17.89	0.33
NP	165.8	111.8	54.0	15.05	14.68	0.37	385.2	268.0	117.2	18.16	17.36	0.80
PK	126.0	95.5	30.5	13.76	12.69	1.07	320.9	217.4	103.5	17.12	16.17	0.95
NK	194.8	172.7	22.1	15.73	15.26	0.47	447.8	348.2	99.6	18.77	17.90	0.87
O	139.8	122.1	17.7	14.26	13.09	1.17	295.4	238.0	57.4	16.98	16.68	0.30
P	136.4	105.4	31.0	14.81	13.43	13.8	320.3	271.6	48.7	16.84	16.41	0.43
N	186.0	194.4	—8.4	15.54	15.45	0.09	352.6	326.4	26.2	18.14	17.46	0.68
K	108.2	115.7	—7.5	13.33	13.34	—0.01	247.4	311.6	—64.2	17.06	16.95	0.11
Av.	152.5	133.0	19.5	14.73	14.12	0.61	346.0	282.4	63.6	17.66	17.10	0.56
Av. percentage increase*			14.66	—	—	—	—	—	22.50	—	—	—

Calcium (Elemental)

NPK	5.12	3.98	1.14	0.50	0.43	0.07	12.52	6.58	5.94	0.54	0.42	0.12
NP	5.14	3.18	1.96	0.49	0.43	0.06	11.12	5.80	5.32	0.51	0.40	0.11
PK	5.37	3.38	1.99	0.60	0.45	0.15	10.88	5.26	5.62	0.52	0.38	0.14
NK	6.40	4.40	2.00	0.54	0.41	0.13	13.22	7.33	5.89	0.49	0.39	0.10
O	5.80	3.79	2.01	0.60	0.41	0.19	9.90	5.37	4.53	0.52	0.36	0.16
P	6.40	4.51	1.89	0.71	0.57	0.14	10.62	8.81	1.81	0.53	0.52	0.01
N	5.52	5.10	0.42	0.48	0.42	0.06	9.62	7.04	2.58	0.49	0.39	0.10
K	4.59	4.60	—0.01	0.57	0.53	0.04	7.66	9.36	—1.70	0.52	0.49	0.03
Av	5.54	4.12	1.42	0.56	0.46	0.10	10.69	6.94	3.75	0.52	0.42	0.10
Av. percentage increase*			34.61	—	—	—	—	—	53.99	—	—	—

Phosphorus (Elemental)

NPK	3.77	3.44	0.33	0.36	0.35	0.01	9.95	6.49	3.46	0.45	0.40	0.05
NP	3.88	2.62	1.26	0.35	0.34	0.01	9.18	6.13	3.05	0.43	0.40	0.03
PK	3.32	2.40	0.92	0.36	0.32	0.04	9.32	5.71	3.61	0.48	0.42	0.06
NK	4.02	3.50	0.52	0.32	0.31	0.01	11.42	6.64	4.78	0.48	0.36	0.12
O	2.82	2.61	0.21	0.30	0.28	0.02	7.69	4.93	2.76	0.43	0.34	0.09
P	3.02	2.60	0.42	0.33	0.33	0.00	8.56	7.08	1.48	0.48	0.43	0.05
N	3.49	3.95	—0.46	0.29	0.31	—0.02	7.88	6.79	1.09	0.44	0.38	0.06
K	2.22	2.74	—0.52	0.27	0.31	—0.04	6.18	7.24	—1.06	0.48	0.39	0.09
Av	3.32	2.98	0.34	0.32	0.32	0.004	8.77	6.38	2.39	0.46	0.39	0.07
Av. percentage increase*			11.23	—	—	—	—	—	37.58	—	—	—

*These percentages are based on the complete averages, not the "rounded off" ones given in the tables.

23.01% in the amount of calcium in the herbage from the limed plats and in 1931 this increase was 22.99% of the average percentage of calcium in the herbage from the unlimed plats. The corresponding increases in the percentage of phosphorus in the herbage from the limed plats in 1930 and 1931 were 1.18 and 17.63, respectively. The 1931 crop was superior in most cases to that of 1930 in both yield and composition.

EFFECT OF CERTAIN FERTILIZER CONSTITUENTS ON COMPOSITION OF HERBAGE

A comparison of the effect on the chemical composition of the herbage of a given fertilizer element in one series of treatments and of its absence in another series may be made for all the plats from which the herbage has been analyzed. It is thought best, however, to omit the pasture mixture plats and all mixed stands from such a study because the effect of the varying botanical population might obscure the effects on the composition of the plants themselves. Chemical analyses of the herbage from pure stands of both Kentucky bluegrass and white clover are available for two cuttings of each in 1930 and for six cuttings of the former and four of the latter in 1931.

All of these plats received an application of lime, hence the effect of lime on the composition is not discoverable.

By referring to Fig. 1 it will be noted that there are for each crop four fertilizer treatments which do and four which do not include a given fertilizer element, thus the averages are of four values for each cutting. These average percentages are shown in Table 2.

Since the percentages listed are all based on water-free material, the average percentage of dry matter in the herbage is shown in Table 2 not because it is supposed that the fertilizer has an appreciable effect on the percentage of dry matter, but in order that any one interested may be informed regarding the base used in calculating the percentages of protein, calcium, and phosphorus. The slight decrease in the percentage of dry matter is hardly significant and is not considered in the discussion.

In the average percentage of increase in crude protein, calcium, and phosphorus for the 2 years, it will be noted that the presence of each of the three elements in the fertilizer has increased the percentage of all the above nutrients in the herbage with the exception of calcium when nitrogen was included. The average shows a decrease of calcium in both Kentucky bluegrass and white clover apparently due to the effects of the nitrogen fertilizer. As is to be expected, the largest increases in the relative percentages are due to the effects of any given element in the fertilizer on that same element in the herbage.

In speaking of the effect of certain fertilizer elements on the herbage of plats of Kentucky bluegrass and white clover in the following discussion, it must be remembered that as indicated in the beginning of the article, nitrogen was supplied in the form of nitrate of soda and besides the nitrogen sodium is also included in the nitrogen carrier; that phosphorus applied as superphosphate included a certain amount of calcium sulfate; that potassium applied as muriate of potash pro-

TABLE 2.—*The effect of including nitrogen, phosphorus, or potassium in fertilizers on the percentage of crude protein, calcium, and phosphorus in the water-free herbage of Kentucky bluegrass and white clover.*

Fertilizer elements	Herbage constituents	Average percentage *with* indicated element in the fertilizer		Average percentage *without* indicated element in the fertilizer		Increase* in percentages of constituent		Percentage† which increase is of the average of plats *not* receiving element		
		1930	1931	1930	1931	1930	1931	1930	1931	Average
				Kentucky Bluegrass						
Nitrogen	Dry matter	27.9	29.0	30.4	30.5	—2.5	—1.5	—8.22	—4.83	—6.52
	Crude protein	18.43	18.77	15.04	16.49	3.39	2.28	22.58	13.79	18.19
	Calcium‡	0.41	0.52	0.44	0.50	—0.03	0.02	—7.34	4.50	—1.42
	Phosphorus‡	0.37	0.44	0.34	0.43	0.03	0.01	8.82	3.51	6.17
Phosphorus	Dry matter	28.9	29.2	29.4	30.4	—0.6	—1.2	—1.87	—3.71	2.79
	Crude protein	16.76	18.00	16.70	17.26	0.06	0.74	0.39	4.35	2.37
	Calcium	0.50	0.53	0.36	0.49	0.14	0.04	40.14	7.61	23.88
	Phosphorus	0.40	0.49	0.31	0.38	0.09	0.11	30.89	27.45	29.17
Potassium	Dry matter	28.7	29.2	29.6	30.4	0.9	—1.2	—3.04	—4.03	—3.54
	Crude protein	16.86	17.78	16.60	17.48	0.27	0.30	1.63	1.77	1.70
	Calcium	0.46	0.52	0.40	0.50	0.06	0.02	13.29	5.53	9.41
	Phosphorus	0.36	0.45	0.36	0.42	0.00	0.03	0.00	5.92	2.96
				White Clover						
Nitrogen	Dry matter	19.5	21.0	20.2	18.0	—0.7	3.0	—3.83	16.81	6.49
	Crude protein	27.53	30.28	25.34	31.22	2.19	—0.94	8.63	—3.00	2.81
	Calcium	1.34	1.34	1.40	1.51	—0.06	—0.17	—4.29	—10.78	—7.54
	Phosphorus	0.39	0.44	0.34	0.46	0.05	—0.02	15.44	—5.43	5.00
Phosphorus	Dry matter	19.2	20.0	20.6	19.1	—1.4	0.9	—6.93	4.59	—1.17
	Crude protein	27.61	30.29	25.27	31.21	2.34	—0.92	9.25	—2.94	3.16
	Calcium	1.42	1.47	1.32	1.38	0.10	0.09	7.18	6.33	6.76
	Phosphorus	0.42	0.47	0.31	0.42	0.11	0.05	36.29	10.59	23.44
Potassium	Dry matter	18.9	18.8	20.8	20.2	—1.9	—1.4	—9.01	6.57	—7.79
	Crude protein	26.99	30.47	25.89	31.02	1.10	—0.55	4.26	—1.76	1.25
	Calcium	1.39	1.40	1.35	1.45	0.04	—0.05	3.34	—3.95	—0.30
	Phosphorus	0.38	0.45	0.36	0.44	0.02	0.01	6.34	2.26	4.30

*Values marked with a minus sign are decreases in either yield or percentage.
†These percentages were obtained by the use of the complete averages, not the "rounded off" ones in the table.
‡Elemental calcium and phosphorus in each case.

vides a certain amount of chlorine; and that there were impurities in each of the fertilizer materials used. In speaking of the effects of the fertilizer, however, only the usual fertilizer element of the compound is considered.

In the herbage of Kentucky bluegrass from the plats where a nitrogen fertilizer was applied there was an average for the 2 years of 18.60% of crude protein, while on the plats which did not receive nitrogen in the fertilizer there was only 15.76% of crude protein in the herbage. On the white clover plats the effect of an application of nitrogen fertilizer was insignificant. The herbage from the plats which received such a fertilizer had 28.90% crude protein, while those which did not receive nitrogen had 28 28% crude protein in the herbage.

The herbage from the plats of Kentucky bluegrass which received an application of fertilizer containing superphosphate had 0.445% of phosphorus, while those plats which did not receive a phosphorus fertilizer had 0.345% of phosphorus in the herbage. White clover plats which received an application of fertilizer containing phosphorus produced herbage having 0.445% of phosphorus, while the plats of white clover not receiving a phosphorus fertilizer produced herbage with 0.365% phosphorus.

No determination of the potassium in the herbage was made; therefore, a statement regarding the effect of the potash fertilizer on the percentage of potassium in these crops is not possible.

The effect of nitrogen, phosphorus, or potassium fertilizers on other elements in the herbage is apparently of little importance, except the effect of nitrogen and phosphorus fertilizers on the calcium content of the herbage. The data indicate that the application of a nitrogen fertilizer results in a decrease of the calcium content of the crop, but the situation in respect to calcium where the crop has been treated with a fertilizer having superphosphate as a constituent is different. Plats of white clover which did not receive an application of nitrogen fertilizer produced herbage with a calcium content of 1.455, while the herbage of the treated plats had only 1.340% of calcium. There was a similar but insignificant difference in the herbage of the untreated and treated plats of Kentucky bluegrass. Plats of Kentucky bluegrass which did not receive superphosphate in the fertilizer had 0.425% of calcium in the herbage, while those which received superphosphate in the fertilizer had 0.515%. The plats of white clover receiving an application of superphosphate in the fertilizer produced herbage with 1.445% of calcium, while those plats which did not receive superphosphate in the fertilizer produced herbage with only 1.350%. The calcium in the superphosphate may have been responsible for at least a part of this increase.

The need for a duplication of plats in work of this kind is recognized but duplication of plats multiplies the chemical work to a point where the available funds are not adequate to provide necessary workers. No attempts have been made to apply statistical tests of significance to these data. It is being collected and is here presented largely as a preliminary survey in order to determine the particular phases of this field of pasture research which are likely to be most productive in an intensive study to be begun later.

SUMMARY

The yield and composition data for the 1930 and 1931 pasture mixtures are presented in such a way as to show the effects of an initial application of 4 tons of limestone per acre in addition to annual applications of certain fertilizer elements on the yields and percentages of dry matter, crude protein, calcium, and phosphorus. Data for Kentucky bluegrass and white clover are presented to show the effects of annual applications of nitrogen, phosphorus, and potassium on the composition of these plants in pure stands.

In general the yield is influenced to a greater extent than the composition. These results should be evaluated with due regard to the amount and distribution of rainfall in the different years.[3]

Lime applied in the fall of 1928 increased the average yield per acre in 1930 and 1931, respectively, as follows: Dry matter, 9.53% and 20.69%; protein, 14.66% and 22.5%; calcium, 34.61% and 53.99%; and phosphorus, 11.23% and 37.58%. In each case the percentage difference is calculated on the average of the unlimed plats.

Among the several treatments nitrogen alone and potassium alone, both of which yielded well in the series of treatments without lime, gave either small or negative response to lime. In fact no other treatments gave smaller yields with than without lime. Treatments NP and PK, both of which yielded poorly in the unlimed series, gave the largest increases due to lime.

The application of lime had little effect on the chemical composition except in the percentage of calcium which was 0.46 in the herbage of the unlimed and 0.56 in that of the limed plats in 1930, and in the same order 0.42 and 0.52 in 1931. The phosphorus content was unchanged by lime in 1930, but in 1931 there was 0.39% of phosphorus in the herbage from the unlimed plats and 0.46% in that from the limed plats.

The effects on the chemical composition of the herbage of including nitrate of soda, superphosphate, or muriate of potash in the treatments of pure stands of Kentucky bluegrass are as follows: Applications of a nitrogen containing fertilizer increased the percentage of crude protein in the crop but apparently had a depressing effect on the calcium content of the herbage.

The presence of superphosphate in the fertilizer increased both the phosphorus and calcium contents of the herbage.

[3]For rainfall records see Vinall, H. N., and Hein, M. A. Seasonal production of grasses and legumes at Beltsville, Maryland, in 1931. Jour. Amer. Soc. Agron., 25: 588–594. 1933.

THE EFFECT OF CERTAIN CROPS ON SUCCEEDING CROPS[1]

T. E. ODLAND and JOHN B. SMITH[2]

That certain crops have a decided influence on those that follow has been recognized for a long time, but the determination of the reasons for these after effects has been a difficult problem to solve. In some instances the causes seem to have been fairly definitely determined, while in others no very clear cause has been located. At the Rhode Island Agricultural Experiment Station considerable work has been done on this problem during the last 25 years. It will be the purpose of this paper to present a brief summary of some of the results obtained in these experiments and to point out some factors that appear to be involved in causing some of the after effects noted.[3]

The various explanations offered by different investigators for the effect of certain crops on succeeding ones may be grouped as follows:

1. Crops that remove excessive quantities of mineral elements tend to impoverish the soil for those elements.

2. Crops that remove the greatest excess of elements that are chemically basic over those that are acidic create the greatest degree of soil acidity and correlated toxicity.

3. Crops that provide residues relatively high in carbohydrates and low in nitrogen are decomposed by micro-organisms at the expense of soil nitrogen, decreasing the supplies available to crops.

4. Certain crops may excrete organic toxins from the roots, or the decomposition of plant residues may leave organic toxins in the soil temporarily or permanently.

EXPERIMENTAL RESULTS

The original experiment at the Rhode Island Experiment Station on the influence of crop plants on those that follow was started in 1907. This experiment is being continued in accordance with the original plans with a few modifications.

In this experiment 16 different crops are grown for 2 years and then followed by a uniform crop or crops over the entire area the third year. Previous to 1930, only a single uniform crop was grown every third year. In that year four uniform crops were grown in duplicate strips across all plats. Commercial fertilizers have been used alike on all plats each year. Lime was applied to all plats at the beginning of the experiment and at three different times since, the last applica-

[1]Published by permission of the Director of the Rhode Island Agricultural Experiment Station, Kingston, R. I., as Contribution No. 434 of the Station. Also presented at the annual meeting of the Society held at Washington, D. C., November 18, 1932. Received for publication December 12, 1932.

[2]Agronomist and Chemist, respectively. In assembling and presenting the material in this paper the senior author has been responsible for the general arrangement and discussion and the junior author for the chemical determinations and the presentation of an interpretation of their bearing upon the general problem. The authors wish to express their indebtedness to F. K. Crandall, F. R. Pember, D. E. Frear, and D. R. Willard for assistance with the field, greenhouse, and chemical work.

[3]The data on which this paper is based are being prepared for publication in a station bulletin and therefore only a summary is presented here.

tion being made in 1917. The plats are being allowed to become more acid gradually in order to enhance the deleterious effects observed after certain crops. At present the pH varies between 5 and 6.

In 1930, when four different crops, *viz.*, corn, potatoes, rutabagas, and mangels, were grown across all plats, variations in yields were obtained as shown in Table 1.

The yields of corn ranged from 76 bushels per acre following corn to 108 bushels following oats. The season was very favorable for corn and high yields were the rule. Except for corn following corn all yields were above 90 bushels per acre.

TABLE 1.—*Minimum and maximum yields following each of 16 different crops in 1930.*

Crop	Minimum yield per acre			Maximum yield per acre	
	Yield	Percentage of maximum	Preceding crop	Yield	Preceding crop
Corn	76 bu.	71	Corn	108 bu.	Oats
Rutabagas . .	417 bu.	46	Rutabagas	900 bu.	Cabbage
Mangels . . .	11.5 tons	36	Mangels	32.1 tons	Potatoes
Potatoes . .	324 bu.	70	Cabbage	466 bu.	Squash

The yields of rutabagas ranged from 417 bushels per acre following a preceding crop of rutabagas to 900 bushels following cabbage. With this crop there was a very decided influence from preceding crops.

Mangels varied in yield from 11.5 tons per acre following a previous crop of mangels to 32.1 tons following potatoes. The yields were depressed the most following red clover, alsike clover, and millet. The detrimental effect of mangels on succeeding crops of mangels has been often noted at this station.

The yields of potatoes following the various crops ranged from 324 bushels per acre following cabbage to 466 bushels per acre following squash.

Previous to the uniform crops grown in 1930, each of the individual crops except carrots had been grown on their designated plats 14 times. Ten crops of carrots had been grown. Any permanent detrimental effects of certain crops should have become established before that time. No crop showed any consistent detrimental effect on all four crops grown in 1930.

A summary of the results obtained with all the uniform crops grown on the plats since the experiment was established is presented in Table 2.

In obtaining the figures for this table the yields of the uniform crops on each plat have been rated in relation to the greatest and smallest yields for that season by dividing the spread between the largest and smallest yields into four equal parts. Yields in group I were depressed less than 25% of the maximum for that season, those

TABLE 2.—*Sixteen crops rated according to effect on various succeeding crops.**

Succeeding crop	Onions	Buckwheat grain	Alsike clover	Mangels†	Carrots	Timothy‡	Potatoes	Corn	Rutabagas	Mangels
Year	1910	1913	1916	1920	1923	1927	1930	1930	1930	1930
Maximum depression, %	86	87	35	39	31	28	30	29	54	64
Rating after:										
Onions	III	II	II	*I*§	I	*I*	III	I	II	I
Potatoes	IV	II	I	*I*	II	*IV*	III	I	II	I
Mangels	IV	II	II	*IV*	II	*III*	III	I	IV	IV
Rutabagas	IV	I	II	*I*	I	*IV*	III	I	IV	I
Cabbage	IV	II	II	*I*	III	*II*	IV	I	I	II
Buckwheat	IV	III	II	*I*	III	*I*	III	I	IV	II
Corn	III	IV	II	*I*	II	*I*	III	IV	III	II
Millet	II	IV	II	*I*	II	*III*	IV	II	IV	III
Oats	II	III	II	*I*	IV	*I*	I	I	III	II
Rye	III	II	I	*I*	III	*I*	I	II	III	II
Carrots			III	*I*	IV	*II*	III	II	III	III
Redtop	I	IV	I	*I*	III	*III*	I	I	II	II
Timothy	II	IV	II	*I*	II	*IV*	II	II	III	III
Squash	II	II	I	*I*	II	*III*	I	II	I	I
Alsike	I	IV	IV	*I*	III	*IV*	IV	I	III	III
Red Clover	III	IV	IV	*I*	III	*IV*	IV	I	IV	IV

*I = Succeeding crop depressed 0 to 25% of the maximum depression noted for that crop; II = Succeeding crop depressed 26 to 50% of the maximum depression; III = Succeeding crop depressed 51 to 75% of the maximum depression; and IV = Succeeding crop depressed 76 to 100% of the maximum depression.

†Liming overcame depressive effects of previous crops except mangels.

‡Second year of timothy. First year not a pure stand but may have modified effects of the different crops grown previously.

§Ratings printed in *italics* should be given less emphasis than the remainder of the data.

of group IV at least 75% of the maximum, while those in groups II and III were intermediate.

From the results presented in this table it is apparent that no one crop can be classed as uniformly unfavorable or uniformly favorable to all succeeding crops. This raises the question whether any one factor can be chiefly responsible for the detrimental effects noted from certain preceding crops. If only a single factor were involved and if this factor be governed in different degree by various crops, the effects on each of the 10 uniform succeeding crops that are influenced by this factor should show the same relationships among the 16 plats. For example, if a plant toxin is produced in the soil to a greater extent by growing carrots than by growing onions, all following crops that are affected by the toxin should be depressed after carrots more than after onions. If oats were intermediate in production of the toxin, yields following oats should be intermediate. An alternative must be granted in the special case of toxins that may stimulate at certain concentrations and become poisonous at greater concentrations, but even such an effect should lead to a definite pattern in results if but one factor is operative. On the other hand, if more than one factor is involved significantly, it is almost certain that the varied responses of different plant species will destroy the uniformity that would result from a single factor. The results indicate on this basis that more than one factor is operative.

SOIL ACIDITY AND CROP EFFECTS

In previous work at the Rhode Island Experiment Station indications have been noted that the removal of certain crops tends to leave the soil more acid than the removal of other crops. The crops that have had a tendency to create the more acid conditions in the soil have also been observed, generally, to have the more detrimental effects on certain succeeding crops.

The various phases of the acidity factor have been studied further during the period covered by this report. The acidity of the soils of the various plats has been determined each fall by measurements of the pH, using the quinhydrone electrode, and by the Jones calcium acetate lime requirement method.

The pH of fresh soil taken from the various plats in the fall of 1929 varied from 5.42 following red clover to 5.85 following rutabagas. The lime requirement varied from 1,490 pounds per acre following potatoes to 2,201 pounds following carrots. The differences have not been large as these figures show.

In order to find whether any relationship existed between the acidity of the soil and yields of certain crops grown in 1930 on these plats, a number of correlation studies were made. The results of these calculations are shown in Table 3.

Although none of these coefficients are large and their probable errors are relatively great, they are all negative. This indicates that the crops which have tended to increase the acidity of the soil have also tended to cause the more deleterious effect on the yield of succeeding crops.

TABLE 3.—*Correlation between yields of certain crops grown in 1930 and the acidity of the various plats the previous fall, October 23, 1929.*

	Coefficient of correlation
Yield of mangels and lime requirement of soil	-0.560 ± 0.116
Yield of mangels and H-ion concentration	-0.394 ± 0.142
Yield of rutabagas and lime requirement of soil	-0.403 ± 0.141
Yield of rutabagas and H-ion concentration	-0.213 ± 0.161
Yield of potatoes and lime requirement of soil	-0.204 ± 0.162
Yield of potatoes and H-ion concentration	-0.239 ± 0.159
Yield of corn and lime requirement of soil	-0.613 ± 0.105
Yield of corn and H-ion concentration	-0.290 ± 0.154

RELATIVE ACID-BASE BALANCE AND CROP EFFECTS

As has been noted previously, preliminary work indicated the possibility that certain crops remove from the soil relatively more basic than acidic elements and thus affect succeeding crops deleteriously. This is also the most logical manner in which different crops could cause permanent changes in soil acidity.

A careful study of the various data that might be correlated with removal of soil bases reveals no significant correlation with soil pH, a low positive correlation with lime requirement, and that there was a tendency toward larger yields of four succeeding crops in 1930 where excess base removals the previous 2 years were relatively low. The greatest removal for this period was equivalent to only 276 pounds of lime per acre and the least removal was 12.5 pounds. Potatoes, onions, and oats form a group, low in excess bases over acids, and beneficial to corn, rutabagas, mangels, and potatoes that followed them in 1930. The remainder of the crops do not fall in line sufficiently to afford significant correlations.

Calculating the nitrogen in the crops as an acidic element, overcoming the basicity of the ash, the magnitudes of the excess acidic elements removed in 2 years in terms of lime ranged from 16.5 pounds per acre to 282.6 pounds. The data relating to soil acidity, plant growth, and acid-base balance of a uniform succeeding crop were not correlated with removals of an excess of acidic elements when nitrogen was included to a greater extent than when only the ash elements were considered.

If soil nitrogen is potentially an acid, this work indicates that the resultant of cropping is to decrease soil acidity for the balance in removal of elements by the crops studied was acid. Yet, soils tend to become more acid with time, as is well known, because of the removal of basic elements by leaching. Assuming the accuracy of the balance as found in this work, leaching and weathering must be more effective agents in the creation of soil acidity than is cropping.

DEPLETION OF NUTRIENTS AND CROP EFFECTS

The excessive depletion of the soil for certain elements caused by a high relative removal by certain crops is often brought forward as a reason for growth differences in a following crop. Nitrogen is the element most frequently under suspicion, and the result on subsequent crops is the same whether the deficiencies are caused by removal in the preceding crop or by absorption during the decomposition of low-nitrogen crop residues by micro-organisms.

In the long-time experiment under discussion, the factor of relative nutrient exhaustion has been thoroughly recognized and eliminated in so far as possible by liberal fertilization, alternation of tilled and untilled uniform crops, and liming. Nitrogen and dry matter were determined in the portions of nine different crops taken from as many plats during a 2-year period. The nine crops selected are all cultivated crops and those that made a normal growth during the 2 years preceding the uniform crops in 1930. The range in nitrogen removal varied from 73.7 pounds per acre over the 2-year period for onions to 187.6 pounds for the same period for corn.

In order to show possible relationships between the amount of dry matter or nitrogen removed by crops and the yields of succeeding crops, the data have been arranged as shown in Table 4. The "nitrogen reserve" was obtained by subtracting the calculated nitrogen removal of the different crops from that calculated for corn which showed the greatest removal. This "reserve" is not analogous to an application of readily available nitrogen for a portion may well have disappeared in winter losses, but to some extent it must represent a supply available to the succeeding crop.

TABLE 4.—*Relationships between the removal of organic matter and nitrogen by various crops during 2 years and the yields of each of four uniform crops the third year.*

Plat No.	Crop	Relative removal of dry matter in 2 years	Nitrogen reserve, pounds per acre*	Corn, bu.	Rutabagas, bu.	Mangels, tons	Potatoes, bu.
91	Corn	100	0.0	76.3	565.1	23.32	391.0
95	Carrots	54	21.5	92.6	577.4	20.32	361.5
92	Millet	96	22.7	93.9	480.8	17.40	327.5
89	Cabbage	42	25.2	101.2	899.8	26.10	324.5
87	Mangels	48	25.5	100.0	506.0	11.47	369.0
90	Buckwheat	68	41.5	100.8	527.5	23.80	362.5
93	Oats	49	109.8	107.7	636.7	22.95	462.5
86	Potatoes	33	111.3	107.5	672.0	32.10	382.5
85	Onions	25	113.9	101.2	762.7	28.12	390.5

*Difference between maximum removal of nitrogen by corn and removal by the various crops for the 2-year period, 1928–29.

In the case of corn there is a significant degree of correlation between the nitrogen reserves calculated in this way and crop yield. With the other three crops the evidence is not definite either way.

In further confirmation of the belief that nitrogen was not the limiting factor for mangels, nitrate determinations in soil taken from

the various plats on July 31, 1930, when the mangels were half grown, showed 27 p.p.m. of nitrate nitrogen where mangels followed mangels, 10 p.p.m. following both alsike and red clover, and a maximum of but 6 p. p. m. on the remainder of the plats, except the area following oats where there were 20 p. p. m. Yet the mangels and clover areas produced notably small yields of mangels. On August 7 there remained 9 p. p. m. of nitrate nitrogen on the mangels area and mere traces following buckwheat, corn, rutabagas, onions, and potatoes. Following millet there were 11 p. p. m. with the remainder of the plats unsampled.

Calcium, an element often considered to be associated with nitrogen in its rate of intake by plants, is negatively correlated with yields of mangels, showing that this element is not the limiting factor and suggesting that the calcium supply was not the decisive factor in overcoming the effects of preceding crops when very uniform yields of mangels were secured over the entire area after heavy liming, except for mangels following mangels.

The results for magnesium are entirely inconclusive and knowledge of the effects of this element must await further evidence. Also, there is no apparent correlation between the acid-base balance of the ash elements of mangels and the yields of that crop.

SUMMARY

During the period of 1907 to 1930, 10 uniform crops were grown following each of 16 different crops. In some years very striking differences in yields of the uniform crop following various preceding crops have been obtained. At other times these differences have not been as large. The yields of these uniform crops have been summarized.

Evidently more than one factor is operative in causing the differences in crop growth noted. The evidence is not clear cut enough to indicate any factor as sufficiently predominant to cause differences of the magnitude noted.

Variations in soil acidity caused by the growth of different crops show sufficient agreement with subsequent growth of other crops to prove that this is an important factor.

Lesser removals of excess basic materials from the soil by previous crops tended to be associated with increased yields of succeeding crops.

The evidence indicates that in the case of corn the relative nitrogen removal of the preceding crops was correlated with yield. This factor, however, was not the dominant one with mangels. The results with the other crops are not conclusive with respect to the importance of differences in nitrogen supply as a factor.

Studies on the effect on crop growth of leachings from soil where certain crops were grown have not yielded consistent enough results to indicate whether soil toxins are involved.

AMMONIUM HYDROXIDE VERSUS CALCIUM NITRATE FOR COTTON SEEDLINGS[1]

J. W. TIDMORE[2]

Recently, Tiedjens[3] used ammonium sulfate, ammonium hydroxide, and calcium nitrate as sources of nitrogen in sand cultures to grow cotton from the seedling stage to opening of the bolls. He stated, "At no time was there any indication of injury to the plants, even though there was a perceptible odor of ammonia coming from the ammonia cultures. ...... If there is any superiority between the two forms of nitrogen, it is in favor of the ammonia cultures." For the above statements to be significant it is necessary to know the composition of the nutrient solution used. Tiedjens[4] stated that the nutrient solutions used for cotton were identical with solutions A, F, and I given on page 12 of New Jersey Agricultural Experiment Station Bulletin 526. Each of these solutions contained approximately 600 p.p.m. of PO_4 as KH_2PO_4. They were, therefore, highly buffered and the cultures to which ammonium hydroxide was added contained, in all probability, ammonium salts instead of ammonium hydroxide.

It is not surprising that cotton plants grew well in a nutrient solution as concentrated as that used by Tiedjens. However, it should be surprising to find that plants tolerated large amounts of ammonium hydroxide in solutions dilute enough to approximate the concentration of a normal soil solution. Probably no soil solution contains as much phosphate as the nutrient solution used by Tiedjens. No mention was made of the probable effect of ammonium hydroxide on plants if they had been placed in a medium with a salt concentration which corresponds somewhat to that of the soil solution.

In order to elucidate this question an investigation in which cotton seedlings were used was conducted to study the following points: (1) The efficiency of different amounts of ammonium hydroxide and calcium nitrate in dilute nutrient solutions, and (2) the efficiency of ammonium hydroxide and calcium nitrate in nutrient solutions with various concentrations of other salts.

Cotton seedlings which germinated in sand were grown in duplicate cultures for 10 days in 2-quart vessels of nutrient solution. The solutions were changed daily. The composition of the nutrient solution, except the nitrogen content, was as follows: PO_4, 12 p.p.m.; K, 3.6 p.p.m.; Ca, 3.5 to 112 p.p.m.; Mg, 2.3 p.p.m.; and SO_4, 9.1 p.p.m.

The sources of nitrogen and nitrogen contents are indicated in Fig. 1. With the exception of the nitrogen content, this solution was approximately 1/50 as concentrated as Tiedjens' solution A, and it

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication Jan. 4, 1933.

[2]Soil Chemist.

[3]TIEDJENS, V. A. Growing cotton and other crop plants with ammonium nitrogen. Science, 75:648. 1932.

[4]Private communication.

was more concentrated, especially with respect to phosphate, than most of the soil solutions of the southeast.

Typical results of this test are shown in Fig. 1. It will be noticed that the plants which received 78.4 p.p.m. of nitrogen as ammonium hydroxide made no growth. Seedlings placed in this solution wilted within 10 hours and they were practically dead 10 days later. The root systems of these plants were dark brown in color and contained no secondary roots. On the other hand, the plants in the solution which received 78.4 p.p.m. of nitrogen as calcium nitrate made some growth and were in a good condition at the end of the 10-day period. In this dilute nutrient solution, ammonium hydroxide was injurious even when the nitrogen concentration was reduced to 19.6 p.p.m. In these cultures the plants, especially the root systems, were in an

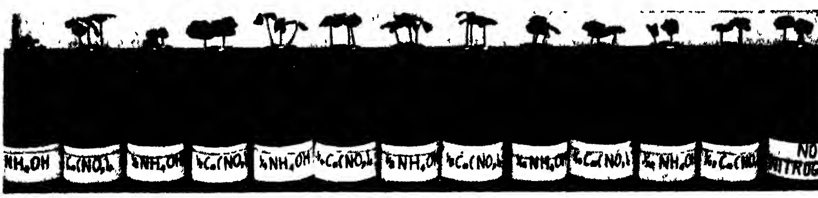

FIG. 1.—Cotton seedlings grown in dilute nutrient solutions to which was added NH_4OH or $Ca(NO_3)_2$ as indicated. NH_4OH or $Ca(NO_3)_2$ = 78.4 p.p.m. N; ½ NH_4OH or ½ $Ca(NO_3)_2$ = 39.2 p.p.m. N; ¼NH_4OH or ¼ $Ca(NO_3)_2$ = 16.6 p.p.m. N, etc.

unhealthy condition. The plants which received 19.6 p.p.m. of nitrogen from calcium nitrate were in excellent condition at the end of the 10-day period. When the concentration was 9.8 p.p.m. of nitrogen or less, ammonium hydroxide did not injure the plants, although no growth resulted from either ammonium hydroxide or calcium nitrate. From the results reported above, it is apparent that ammonium hydroxide in the dilute nutrient solution was not a satisfactory source of nitrogen for cotton seedlings.

Tiedjens grew cotton successfully when 78.4 p.p.m. of nitrogen as ammonium hydroxide was added to a nutrient solution many times more concentrated than the average soil solution. Since the soil solution is very dilute and only slightly buffered, ammonium hydroxide might be much more injurious in such a solution than in a concentrated solution. To test this possibility a comparison was made of the efficiency of ammonium hydroxide and calcium nitrate when added to solutions which varied from 75 to 600 p.p.m. in phosphate concentration. The other constituents of the nutrient solutions, except the nitrogen, varied as shown in Table 1. Cotton seedlings were placed in 2-quart jars containing nutrient solutions which were changed daily for a 10-day period.

The results are shown in Fig. 2. In the case of the most concentrated solution (Tiedjens' solution A) it will be observed that ammonium hydroxide produced just as good plants as calcium nitrate. Even though ammonium hydroxide was added, in all probability the plants had access to ammonium salts and not to ammonium hydroxide since

the reaction of the solution was pH 6.55. The plants in solutions 1 and 2 had excellent root systems. When the nutrients (except the calcium nitrate and ammonium hydroxide) of the solutions were

TABLE 1.—*The composition and reaction of nutrient solutions.*

Nutrient solution*	Source of nitrogen	Composition of solutions in p.p.m.						pH
		PO_4	SO_4	Cl	K	Ca	Mg	
1	NH_4OH	600	454	311	183	175	115	6.55
2	$Ca(NO_3)_2$	600	454	112	183	175	115	4.70
3	NH_4OH	300	227	311	92	175	57	7.40
4	$Ca(NO_3)_2$	300	227	112	92	175	57	5.00
5	NH_4OH	150	113	311	46	175	28	8.73
6	$Ca(NO_3)_2$	150	113	112	46	175	28	5.95
7	NH_4OH	75	57	311	23	115	14	9.20
8	$Ca(NO_3)_2$	75	57	112	23	115	14	5.92

*Each culture contained 78.4 p.p.m. nitrogen.

reduced by 50%, ammonium hydroxide caused a very poor growth as compared with that obtained from calcium nitrate. As the salt content of the solution was further reduced the difference between the ammonium hydroxide and calcium nitrate cultures increased. The plants in culture 8 were green and in a healthy condition, whereas those in culture 7 were practically dead. A comparison of the plants in the first culture in Figs. 1 and 2 further shows that ammonium hydroxide was injurious when added to the dilute solution, whereas it was satisfactory when added to the concentrated nutrient solution.

FIG. 2.—Cotton seedlings grown in concentrated nutrient solutions. (See Table 1 for composition in detail.)
Jars 1, 3, 5, and 7 received NH_4OH; 2, 4, 6, and 8 received $Ca(NO_3)_2$.

Tiedjens stated, "The generalization that ammonium hydroxide is toxic to plant growth, under good cultural conditions, is no longer tenable." This statement was made even though ammonium hydroxide was added only to very concentrated solutions. It is clearly shown that the acid phosphate concentration of the nutrient solution must be very high to prevent injury to cotton seedlings by ammonium hydroxide. Excellent growth was obtained with the most concentrated nutrient solution where ammonium hydroxide was added because of

the immediate formation of ammonium salts and practically no growth was obtained where ammonium hydroxide was added to the dilute solution. In sandy soils, which are poorly buffered and contain extremely small amounts of phosphate and other salts, it is entirely possible that when certain fertilizer materials are used free ammonia concentrated in localized areas may injure cotton seedlings.

FACTORS AFFECTING THE ACCUMULATION AND LOSS OF NITROGEN AND ORGANIC CARBON IN CROPPED SOILS[1]

ROBT. M. SALTER and T. C. GREEN[2]

It is generally recognized that both the nature and the size of the crops grown affect the gains or losses of nitrogen and organic matter occurring in field soils. More exact information is needed upon the comparative effects of different crops. Further, the attempt should be made to differentiate between the effects of the cultural practices employed in growing a crop and those of the residues left by it.

In the present report these questions are considered in connection with changes that have taken place in the contents of organic carbon and nitrogen in fertility plat soils at the Ohio Experiment Station. Some data showing the effects of manure also will be presented.

For all experiments cited the soil is the Wooster silt loam, a yellowish brown soil derived from non-calcareous glacial sandstone and shale material, naturally acid and only moderately supplied with organic matter and nitrogen.

COMPARISON OF DIFFERENT CROPS

In Table 1 are presented the nitrogen and organic carbon contents for the surface soils of plats in both continuous and rotative cropping. The data are for check plats continuously untreated except for liming as indicated. Analyses of the soils at the beginning of the experiments are available only for the 5-year rotation experiment. Since there is reason for believing that the soils of all the experiments were closely alike at the start, the foregoing analyses will be employed in estimating the changes that have taken place in all experiments.

Greatest losses of both nitrogen and organic carbon are noted with continuous cropping to corn followed in order by continuous wheat, continuous oats, the 5-year rotation, and the 3-year rotation. In order to obtain a better idea of the comparative effects of the individual crops, these data have been subjected to mathematical analysis involving certain assumptions as discussed below.

The average effect of a given crop in a single year is assumed to be proportional to the soil's content of organic carbon or nitrogen at the beginning of the year. This is based upon the following two assump-

[1]Contribution from the Department of Agronomy, Ohio Agricultural Experiment Station, Wooster, Ohio. Also presented before Section O of the American Association for the Advancement of Science, Atlantic City, N. J., December, 1932. Received for publication December 17, 1932.

[2]Agronomist and Assistant in Agronomy, respectively.

TABLE 1.—*Nitrogen and organic carbon contents of untreated check plats (surface soils, 0 to $6\frac{2}{3}$ inches).*

Experiment	Section	Year	No. of plats	Organic carbon, lbs.			Nitrogen, lbs.		
				Unlimed	Limed	Average	Unlimed	Limed	Average
5-year rotation of corn, oats, wheat, clover, and timothy; begun in 1894	D	1894	10	—	—	20,365	—	—	2,176
	D	1907	10	—	—	—	1,850	—	1,885
	D	1908	10	—	—	—	—	1,930	
	D	1911	10	—	—	—	1,718	1,737	1,727
	D	1921	10	—	—	—	1,566	1,565	1,566
	D	1925	10	15,490	15,490	15,490	1,544	1,548	1,546
Continuous corn; begun in 1894		1913	4	—	—	—	1,090	1,016	1,053
		1925	4	7,370	7,370	7,370	820	860	840
Continuous oats; begun in 1894		1913	4	—	—	—	1,586	1,520	1,553
		1925	4	12,650	13,220	12,935	1,305	1,425	1,365
Continuous wheat; begun in 1894		1913	4	—	—	—	—	1,675	—
		1925	4	—	12,820	—	—	1,315	—
3-year rotation of corn, wheat, and clover; begun in 1897	A	1907	8	—	—	—	—	1,918	—
	A	1925		—	1157.	—	—	1,780	—

*All crops harvested off the land.

tions: (1) That with a given type of culture, determined by the crop, a certain fraction of the total amount of organic carbon or nitrogen in the soil will be lost in a year of cropping, and (2) that the gain in these constituents arising from crop residues will be proportional to the amounts already in the soil since they will vary with the size of crop and the latter will be more or less proportional to the amounts of nitrogen and organic matter present. Obviously these assumptions are only approximations, but it is believed that they apply closely enough on these untreated soils to warrant their use.

Based on the foregoing, the soil's content of either organic carbon or nitrogen, C_t, after "t" years of continuous cropping will be determined by the following equation $C_t = C_0K^t$ (1) where C_0 represents the content of the constituent at the beginning and K the fraction of the constituent remaining after growing the crop a single year. For example, if the net loss in growing a single corn crop is 3% of the amount of nitrogen present at the start, 97% will remain and K will equal 0.97. The same equation may be applied to rotative cropping by making K equal to the mean value for the individual crops of the rotation.

Employing as the C_0 values the contents of organic carbon and nitrogen in the 5-year rotation plats in 1894 and as the C_t values the contents found for the various experiments in 1925, the calculated values for K and for the percentage annual losses are shown in Table 2.

TABLE 2.—*Calculated values for K and percentage annual losses.*

Method of cropping	Organic carbon		Nitrogen	
	K	Annual loss %	K	Annual loss %
Continuous corn*	.9688	3.12	.9707	2.97
Continuous wheat	.9856	1.44	.9844	1.56
Continuous oats*	.9859	1.41	.9855	1.45
5-year rotation*	.9915	0.85	.9894	1.06
3-year rotation	.9940	0.60	.9931	0.69

*Averages for limed and unlimed ends.

It appears that a crop of corn is about twice as destructive of organic carbon and nitrogen as a crop of either wheat or oats and that the introduction of hay crops in the rotative cropping has materially reduced the annual losses of both constituents.

The progressive change in composition with time, calculated from equation (1) employing the values of K in Table 2, is shown for organic carbon in Fig. 1 and for nitrogen in Fig. 2. In the figures compositions are expressed as percentages of the original amounts present. In Fig 2 actual analyses for nitrogen made at intermediate periods are shown and are seen to agree fairly well with the calculated values indicated by the curves.[3] For comparison with Figs. 1 and 2, the trend of crop yields for the continuous culture plats as shown by

[3]The 1894 and 1925 samples were all analysed at the same time and by the same analyst. The other analyses were made at different times, corresponding with the sampling dates.

running 5-year averages placed on a relative basis are presented in Fig. 3. Although the yield trends are generally similar to the calculated trends in nitrogen and organic carbon contents, the decrease in

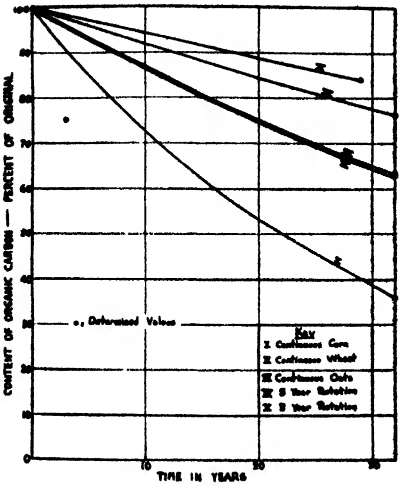

FIG. 1.—Curves showing the calculated progressive change in organic carbon content of unfertilized soils.

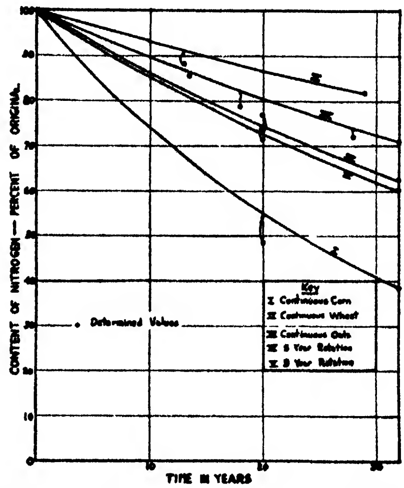

FIG. 2.—Curves showing the calculated progressive change in nitrogen content of unfertilized soils.

relative yields for all crops is somewhat larger than that for the corresponding soil constituents; also, the yield of corn decreases at a faster rate in the earlier years.

The accumulative effects of the hay crops included in the rotation experiments may be estimated by considering that the yearly losses occasioned by the grain crops in these experiments were the same, i.e., the same "K" values, as in continuous culture. Since the land is regularly plowed in preparation for each grain crop in all cases, this assumption is probably justified. Equation (1) may be modified to apply to rotative cropping as follows: $C^t = C^o K_1^{n_1} K_2^{n_2} K_3^{n_3}$ ....(2) where K_1, K_2, K_3, etc., represent the "K" values for the individual crops and n_1, n_2, n_3, etc., the numbers of the corresponding crops grown during t years.

In the 5-year rotation, during the 32-year period (1895 to 1925), there were grown 7 crops of corn,

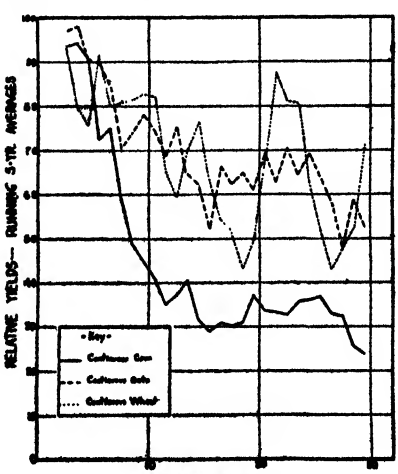

FIG. 3.—Curves showing relative changes in production of unfertilized plats under continuous cropping.

7 of oats, 6 of wheat, 10 of hay, and 1 each of soybeans and millet. Assuming the last two crops as equivalent in their combined effects to two crops of oats, equation (2) may be applied in the following form: $C_{32} = C_0 K_1^7 K_2^9 K_3^6 K_4^{10}$ where K_1, K_2, K_3, and K_4 are, respectively, the "K" values for corn, oats, wheat, and hay. All but K_4 are known and the latter thus readily can be calculated. Similarly, for the 3-year rotation, the following equation applies: $C_{29} = C_0 K_1^{10} K_3^{10} K_4^9$ These equations yield the values given in Table 3 as representing the effects of the hay crops in the two rotations.

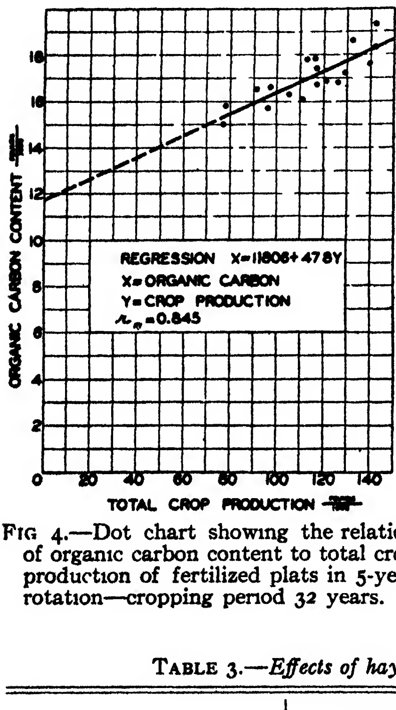

FIG 4.—Dot chart showing the relation of organic carbon content to total crop production of fertilized plats in 5-year rotation—cropping period 32 years.

The lower accumulative effects of the hay crops in the 5-year rotation probably reflect a lower efficiency of timothy than of clover. The values for the 5-year rotation represent averages for both the limed and unlimed ends of these plats. The second year's hay crop on the limed end and both hay crops on the unlimed end are predominately timothy or other non-leguminous plants. All plats in the 3-year rotation are completely limed and the hay crop is regularly almost pure clover. From the data for the 3-year rotation it appears that the accumulative effect of a clover crop on this limed but otherwise untreated soil approximately balances the destructive effect of a crop of corn.

TABLE 3.—*Effects of hay crops in the two rotations.*

	Organic carbon		Nitrogen	
	K	Annual gain %	K	Annual gain %
Hay in 5-year rotation .	1.0136	1.36	1.0064	0.64
Hay in 3-year rotation.....	1.0325	3.25	1.0287	2.87

INFLUENCE OF SIZE OF CROP

The tendency for both organic carbon and nitrogen to be conserved or accumulated more or less in proportion to the size of crops grown has been pointed out by Bear and Salter[4] for fertility plats soils at the West Virginia Station. White[5] has shown that the organic matter

[4]BEAR, F. E., and SALTER, R. M. The residual effects of fertilizers. W. Va. Agr. Exp. Sta. Bul. 160. 1916.

[5]WHITE, J. W. Crop yields in relation to residual soil organic matter. Jour. Amer. Soc. Agron., 23: 429–434. 1931.

contents of fertility plats at the Pennsylvania Station after 40 years of cropping bear a close relation to the crop production of these plats. The same relation is brought out by a study of the data for the Ohio fertility plats. In Fig. 4 is presented a dot chart showing the relation between the amounts of organic carbon in the soils of the limed ends of the fertilized plats of the 5-year rotation and the total yields of crops produced on these plats in the previous 32-year period. The high correlation of these two sets of values is shown by a computed corrêlation coefficient of $r_{xy} = +0.845$. The regression appears closely linear and is described by the equation: $x = 11806 + 45.8\ y$, where x is the content of organic carbon and y the total crop production in thousands of pounds. This equation indicates that for each 1,000 pounds of crops produced the amount of organic carbon increases on the average 45.8 pounds. An interesting and important deduction from this equation is that for zero crop production a content of 11,806 pounds of organic carbon is indicated. This may be interpreted as the amount of organic carbon that would have remained in this soil had the same type of culture been applied without any crops actually being grown. Hence, by employing the regression equation a means is afforded for differentiating between the effects of cultural practices and crop residues. An example will later be given showing how this applies in the case of plats receiving manure.

The correlation coefficients and regression equations for both organic carbon and nitrogen and for both limed and unlimed plats of the 5-year rotation are presented in Table 4.

TABLE 4.—*Correlation coefficients and regression equations relating crop production and composition of 5-year rotation plats.*

	Regression equation*	r_{xy}
Nitrogen:		
Unlimed	$x = 1253 + 4.84\ y$	+0.747
Limed	$x = 1446 + 2.40\ y$	+0.630
Organic carbon:		
Unlimed	$x = 12890 + 46.3\ y$	+0.624
Limed	$x = 11806 + 45.8\ y$	+0.845

*x = pounds per acre of soil constituent.
y = total crop production in thousands of pounds.

In his analysis of the organic matter data for the Pennsylvania plats, White[6] found a decreasing ratio of organic carbon to crops produced in passing from plats of low to high crop yield. He interpreted this as resulting from the stimulation of microbiological destructive processes by the same fertilizer treatments that produced the higher crop yields. He studied the carbon dioxide produced upon the incubation of these soils and the results appeared to support this hypothesis. The authors are inclined to question White's conclusions and to favor a different interpretation. In his treatment of the data no account is taken of the fact that of the organic matter found at the end of 40 years a considerable part was residual from

[6] *Loc. cit.*

that originally present in the soil, and that this residual portion must have constituted a larger fraction of the total organic matter on the low-yielding plats than on the high yielding plats. Had a plat produced no crop whatever the ratio of organic matter to crops produced would necessarily have been infinite. The Pennsylvania data yield a highly significant correlation of $r_{xy} = + 0.851$ between organic matter and crop production with the following regression equation: $x = 71.4 + 0.247\,y$, where x = organic matter and y = crop production, both expressed as percent of the untreated plats. It appears that with the same cultural practices but no crop residues, the organic matter in this soil would still have been approximately 71% of that found in the untreated plats. The regression is closely linear, indicating that a unit of crops produced has contributed essentially the same amount to the soil's supply of organic matter irrespective of the yield. The higher carbon dioxide production under incubation for soils containing larger amounts of crop residues reasonably could be anticipated. The manure plats are omitted from consideration in the foregoing since these doubtless contained organic carbon residual from the manure itself.

COMPARATIVE VALUE OF RESIDUES FROM DIFFERENT CROPS

All of the Ohio experiments, except the 3-year rotation manure experiment, contain in addition to the unfertilized check plats a number of chemically fertilized plats. By determining the mean differences between the contents of organic carbon and nitrogen for the untreated and fertilized plats of each experiment and dividing these differences by the difference in total crop production for the corresponding groups of plats, values were obtained showing the amounts of organic carbon and nitrogen conserved per unit of crops produced. These values are presented in Table 5.

TABLE 5.—*Organic carbon and nitrogen conserved by each 1,000 pounds of crops produced.*

Cropping system	Organic carbon, lbs.	Nitrogen, lbs.
Continuous corn, average limed and unlimed ends*	3.8	0.61
Continuous oats, average limed and unlimed ends*	44.9	4.45
Continuous wheat, limed	26.6	2.81
5-year rotation:		
Unlimed	30.7	2.67
Limed	38.1	4.24

*Crops from two ends not harvested separately.

The relatively small contribution that residues from the corn crops make to the organic matter and nitrogen supplies of the soil is clearly indicated. The oats crop appears somewhat more efficient per unit of crop produced than wheat. The results for the 5-year rotation represent the summation effects of all crops grown, including the

inefficient corn crop and the probably highly efficient hay crops as well as both oats and wheat. The higher efficiency indicated for crops on limed land in this rotation may reflect the influence of the better clover crops grown with liming. It should be noted that the values for the 5-year rotation in Table 5 differ somewhat from those indicated by the regression equations in Table 4 which were determined from data for the fertilized plats only. The authors are able to offer no satisfactory explanation for these differences other than the errors inherent in such a study.

EFFECT OF MANURE

To what extent are the effects of applications of manure upon soil organic matter and nitrogen the result of increased crop residues and to what extent do they represent residues from the manure itself? In Table 6 are presented data for plat 18 of the 5-year rotation affording an approximate answer for the conditions of this experiment. This plat receives 16 tons of manure each rotation divided equally between corn and wheat. During the 32-year period this plat received 234 tons of manure carrying approximately 1,872 pounds of nitrogen and 46,400 pounds of carbon.

TABLE 6.—*An analysis of the effects of manure applied to plat 18 of the 5-year rotation experiment over a 32-year period.*

	Unlimed		Limed	
	Organic carbon, lbs.	Nitrogen, lbs.	Organic carbon, lbs.	Nitrogen, lbs.
1. Content had no crop residues been added*	12,890	1,253	11,806	1,446
2. Additions resulting from crops grown*	5,135	537	6,678	348
3. Excess of 2 over corresponding value for check plats*	2,903	303	2,849	149
4. Sum of 1 and 2	18,025	1,790	18,484	1,794
5. Content actually found	20,090	1,980	21,328	1,980
6. Difference between 5 and 4 = residues from manure applied	2,065	190	2,845	186
7. Total gain for manure, sum of 3 and 6	4,968	493	5,694	335

*Calculated from the regression equations in table 4.

Of the total nitrogen added in the manure approximately 10.1% remains in residual form in the unlimed soil and 9.8% in the limed soil. The corresponding figures for carbon are 4.5 and 6.1%, respectively.

SUMMARY

Data are presented showing the changes that have occurred in the nitrogen and organic carbon contents of fertility plat soils devoted to both continuous and rotative cropping at the Ohio Experiment Station. These data are analyzed and inferences drawn regarding the comparative effects of different crops and the influence of the

size of crop. An attempt is made to differentiate between the effects of cultural practices and those of crop residues. The effects of manure are divided into those arising from the residues of the larger crops grown and those representing residues from the manure itself.

It is estimated that a single year's cropping to the various crops has increased or decreased the organic carbon content of the soil by the following percentages of the total amount present in the soil: corn, —3.12; wheat, —1.44; oats, —1.41; hay in 5-year rotation (timothy predominating), + 1.36; hay in 3-year rotation (clover), + 3.25. The corresponding values for nitrogen are: corn, —2.97; wheat, —1.56; oats,—1.45; hay in 5-year rotation, +0.64; hay in 3-year rotation, +2.87.

The amounts of both organic carbon and nitrogen in fertilized plats of the 5-year rotation experiment were found after 32 years cropping to be highly and positively correlated with the total crop production of these plats. The regressions were apparently linear and from the corresponding equations the amounts of nitrogen and carbon calculated for zero crop production were interpreted as the quantities that would have been found had the same cultural practices been employed but no residues whatever returned. The data of White[7] for fertility plats of the Pennsylvania Experiment Station were found to show a similar relation, indicating a fairly constant contribution of organic matter per unit of crops produced irrespective of the yield.

By comparing the composition of fertilized and unfertilized plat soils of the Ohio experiments, it is concluded that residues from the corn crop were of little value in conserving soil nitrogen or organic matter, those from oats were notably effective, and those from wheat intermediate in value.

Of the nitrogen and organic carbon conserved during 32 years in the soil of a liberally manured plat in the 5-year rotation, it was estimated that about one-half on the limed end and three-fifths on the unlimed end was attributable to residues from the larger crops grown, the remainder being residual from the manure itself.

NOTE

HARVESTING VARIETAL PLATS OF WINTER WHEAT WITH A COMBINE

The varietal plats of winter wheat at the Southern Great Plains Field Station, Woodward, Okla., were harvested with a combine in 1933. One hundred and eight 1/47-acre plats were harvested in about 7 hours with a combine and a crew of three men. This represents a considerable saving of time and labor as compared with cutting with a binder and threshing with a separator, and it is believed that the error is no greater when cut with the combine. It was necessary to wait about 2 minutes between plats, or until grain ceased coming from the hopper. A certain quantity of grain always remained in the

[7] Loc. cit.

machine, but, with the separator "full" of grain at the start, it appeared to clean out to this quantity after each plat, thus giving sufficiently accurate grain yields.

The combine used was an 8-foot-cut Gleaner with an auxiliary motor, mounted directly on a caterpillar tractor. The header at the front of the machine cuts a swath of sufficient width to prevent any damage to adjacent plats. It was not difficult for a skillful driver to cut individual plats 7 feet wide with 19-inch alleys between.

Harvesting in this manner necessitates the growing of an extra series of plats for seed. This series was cut with a binder and threshed with a nursery thresher. Seed of varieties from intensively rogued plats, threshed in a nursery thresher, should be more easily maintained in a pure state than seed from varietal plats cut with a binder and threshed in a larger separator. The time saved in harvesting the yield plats with a combine makes it possible to take extra precautions in handling the series of plats for seed.—EDMUND STEPHENS, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Woodward, Okla.*

AGRONOMIC AFFAIRS

A BIBLIOGRAPHY ON SOIL EROSION

What is described as a partial bibliography on soil erosion has been prepared by Lillian H. Wieland of the Soil Erosion Investigations, U. S. Dept. of Agriculture, Washington, D. C., and is now available in mimeographed form. Approximately a thousand titles are listed.

In an introductory statement to the bibliography, Dr. H. H. Bennett, in charge of the Soil Erosion and Moisture Conservation Investigations of the Department of Agriculture, says, "Not all of the papers deal strictly with erosion, but they all have a pertinent relationship to some phase of the subject. A number of popular articles have been included, particularly because of their bearing on the geographic aspects of erosion. A considerable number of references will reveal only items of historic interest. It is felt that these latter should be included inasmuch as it is believed to be a matter of no small value to know that a few men of vision have sensed the evils of erosion from very early times."

NEWS ITEMS

An attractive illustrated booklet entitled "The Story of the American Potash and Chemical Corporation" has recently been issued by the Corporation in New York City. The booklet describes the development of the extensive plant operated on Searles Lake at Trona, California, and tells something about the products manufactured there. Copies of the booklet may be obtained from the New York Office.

IDE P. TROTTER, Extension Specialist in Field Crops of the Missouri College of Agriculture, was awarded the degree of doctor of philosophy

by the University of Wisconsin in June. His thesis dealt with the effectiveness of the Missouri clover and prosperity program in changing legume practices of Missouri farmers. Ten years of extension work on this agronomic project were studied as to effectiveness on both individuals and groups.

D. A. Anderson, who has been doing research work in soil bacteriology at Iowa State College since receiving the doctor's degree a year ago, has recently been appointed to the staff of Weber College at Ogden, Utah. Dr. Anderson will have charge of the work in chemistry and bacteriology at that institution and will assume his duties there September 1.

S. S. Obenshain and W. H. Willis, who received the doctor's degree in soil fertility and soil bacteriology, respectively, from Iowa State College during the past year, have recently been appointed to positions in connection with the federal reforestation and soil erosion work. Both will be located in Iowa for the next few months.

The University of Illinois has conferred the degree of doctor of philosophy on the following members of the agronomy staff. O. T. Bonnett, Associate in Plant Breeding; R. S. Stauffer, Associate in Soil Physics and Soil Survey; C. A. VanDoren, Assistant in Crop Production; and D. C. Wimer, Assistant Professor and Assistant Chief in Soil Physics. Two men from foreign countries were also granted the degree as follows: Z. H. Patel, who is returning to his home in Palatana, Dt. Kathiawar, India, where he will continue in research work in soils and crops, and Moses Sing-Dung Swen, who will teach at Hopei Provencial College of Agriculture, Paotingfu, Hopei, China.

Dr. Frank T. Shutt of the Dominion Experimental Farms at Ottawa, Canada, and a Fellow of the Society, was one of 42 distinguished American chemists who were guests of honor at a dinner sponsored by the American Chemical Society at the Century of Progress Exposition in Chicago on September 14.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 OCTOBER, 1933 NO. 10

EFFECT OF FERTILIZERS ON IRRIGATED EPHRATA FINE SAND AND APPLE TREE RESPONSE IN THE WENATCHEE ORCHARD DISTRICT[1]

C. A. LARSON[2]

Soil variations arise because of differences in cropping, environment, age, or mode of formation. Although the productivity of orchard soils as well as other soils is influenced by several growth factors that are not controlled by the soil itself, the supply of available plant nutrients is of primary importance, although it is difficult to evaluate. One of the most difficult problems in soil management is to determine the kind and amount of fertilizer necessary to insure continued economical productivity of crops.

In irrigated soils formed under arid conditions, the effect of salts dissolved in the soil solution and those present in the irrigation water may further complicate the fertilizer requirements. It appeared to be advisable, therefore, to make a careful study of an orchard on an irrigated soil receiving fertilizers for the purpose of establishing such definite relationships as may exist between the soil conditions and the resulting plant growth.

PREVIOUS WORK

Since fruit trees differ from ordinary crop plants because of their storage facilities for plant foods, their deep and extensive root system, and their marked periodicity in production, it is often difficult to measure the results of soil treatments in terms of fruit yields. Investigators (10, 3, 9)[3] in New York, for instance, have not found sufficient benefit from fertilizers to recommend their application. The responses obtained may have been masked by the excellent

[1]Contribution from the Division of Agronomy, Soils Section, Washington Agricultural Experiment Station, Pullman, Wash. Part of a thesis presented in partial fulfillment of the requirements for the degree of doctor of philosophy. Published as Scientific Paper No. 222, College of Agriculture and Experiment Station, State College of Washington. Received for publication December 19, 1932.

[2]The author takes this opportunity to express his sincere gratitude and kindly appreciation to Dr. S. C. Vandecaveye and the late Henry F. Holtz for their generous help during the course of this work, and to F. L. Overley for help in sampling.

[3]Reference by number is to "Literature Cited," p. 651.

natural growth of the trees resulting from suitable soil conditions and careful cultural practices.

Workers (6, 11) in West Virginia and Virginia found no consistent beneficial results from the use of fertilizers, but in some cases potassium increased the size and quality of the fruit and applications of nitrogen usually increased the tree growth.

Brown (1) determined the P_2O_5, K_2O, Ca, and N content of apples that were grown on gravelly, silty, and fine sandy soils and found differences well beyond the range of experimental error with the use of the same variety of apples grown during the same season.

The analysis of plant material has been carried out for a number of years as a guide to the nutritional conditions of the soil. Gilbert and Harden (8) concluded that in general the current concentration of mineral nutrients in the juices of crop plants are correlated directly with the application of chemical fertilizers to the soil. There seemed to be a direct relation between the concentration of plant nutrients in the soil solution as influenced by fertilizer applications and the concentration of the same elements in the plants. These investigators suggested the mineral nutrient content of the plant juice as an index of fertilizer needs, and selected tentative concentrations for each nutrient.

Lagatu and Maume (12) found that they could discover the nutritional needs of grapes by the analysis of two leaves at the base of a cluster of grapes. These investigators have added fertilizers to the soil singly and in combinations, and have drawn conclusions from the effect of these fertilizing elements upon the physiological ratio of N, P_2O_5, and K_2O of the leaves. It is obvious from their experimental work that any fertilizing practice which changes the nutrition of the grape plant results in reduced yields if the ratio of nutrients in the leaves is changed from that associated with the best production. Thus they concluded that a balanced ratio of plant food elements in the soil will produce a well balanced ratio of plant food in the leaves followed by high production of fruit.

On the other hand, a deficiency of nutrients in the soil will cause a plant to change its mode of nutrition to the extent that the ratio of plant food in the leaves will also be unbalanced and result in a lower yield of fruit. The data reported by these authors show that an average ratio of 3.7 parts of nitrogen to 1 part of phosphoric acid to 3.4 parts of potash existed in the leaves of the grapes that gave the highest yields. There was considerable variation from these values, however, at different times during the growing season.

In later work, Lagatu and Maume (14) found that the grape plant is not able to take full advantage of a good supply of readily available plant nutrients in the soil after the plant's mode of nutrition has been changed by fertilizer additions which resulted in an unfavorable nutritive ratio.

Murneek and Gildehaus (16) attempted to verify the principles set forth by Lagatu and Maume by growing dwarf apple trees in pure quartz sand cultures. Their results are not in agreement with the latter's work, although these investigators state that a part of the discrepancy between their work and that of Lagatu and Maume is

probably due to the fact that each plant, *Vitis vinifera* and *Pyrus Malus*, absorbs nutrients in different "physiologically balanced" proportions.

From this brief review of previous work elsewhere, it seemed that the best method of approach to this problem was one which embodied a study of both soil and plant materials in order that any relationships existing between the two might be brought out.

EXPERIMENTAL PLAN

A series of fertilized plats located in East Wenatchee on a bench along the Columbia River was used for the experiments. The soil is Ephrata fine sand underlaid with water-washed gravel.

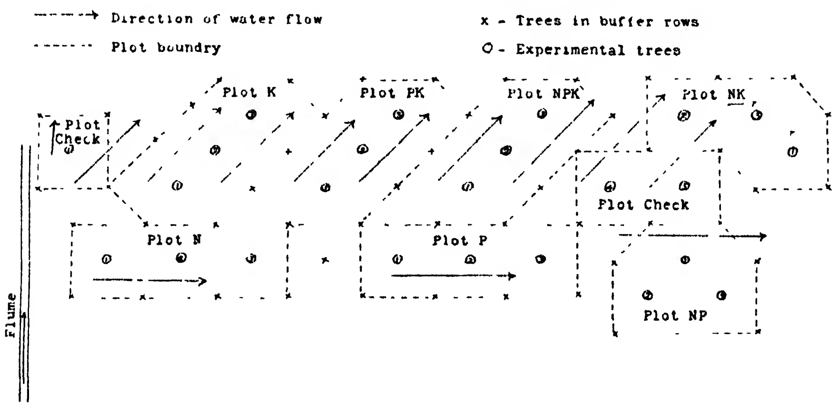

FIG. 1.—The arrangement of the fertilizer plats in the orchard, showing the direction of flow of irrigation water, the buffer trees, and the experimental trees.

The plats were oblong blocks containing three 20-year-old Jonathan apple trees planted 26 feet apart on the alternate system. The trees of the check plat were separated as shown in Fig. 1. One row of trees on the dividing line between adjacent plats was used as a buffer row and the different fertilizer treatments were extended to this dividing line. The ditch system of irrigation was used with three ditches between tree rows. Plats receiving combined applications of nitrogen and phosphorus and nitrogen and potassium were unfortunately located in such a way that the run-off water could not escape as freely as on the other plats, and a little more leaching resulted on these plats. The annual cover crop consisted mainly of an uneven stand of alfalfa interspersed with some grass and weeds.

The first fertilizer treatments of the five original plats were made during the first part of April in 1927, as shown in Table 1. In 1928, two more plats were added receiving applications of nitrogen and potassium and nitrogen and phosphorus, respectively. That year and in the following years the fertilizers were broadcast over the whole plat during the months of January or February.

Leaf samples from bearing and non-bearing spurs were obtained at different periods for determination of the nutrients taken into the tree.

TABLE 1.—*Rate of application of fertilizing materials per tree.**

Year	N	P	K	NK	NP	NPK	PK
1927	5 lbs. ammonium sulfate	6 lbs. superphosphate	5 lbs. potassium chloride			5 lbs. ammonium sulfate 6 lbs. superphosphate 5 lbs. potassium chloride	6 lbs. superphosphate 5 lbs. potassium chloride
1928	5 lbs. ammonium sulfate	6 lbs. superphosphate	5 lbs. potassium chloride	5 lbs. ammonium sulfate 5 lbs. potassium chloride	5 lbs. ammonium sulfate 6 lbs. superphosphate	5 lbs. ammonium sulfate 6 lbs. superphosphate 5 lbs. potassium chloride	6 lbs. superphosphate 5 lbs. potassium chloride
1929	5 lbs. ammonium sulfate	6 lbs. superphosphate	5 lbs. potassium chloride	5 lbs. ammonium sulfate 5 lbs. potassium chloride	5 lbs. ammonium sulfate 6 lbs. superphosphate	5 lbs. ammonium sulfate 6 lbs. superphosphate 5 lbs. potassium chloride	6 lbs. superphosphate 5 lbs. potassium chloride
1930	5 lbs. ammonium sulfate	6 lbs. superphosphate	5 lbs. potassium chloride	5 lbs. ammonium sulfate 5 lbs. potassium chloride	5 lbs. ammonium sulfate 6 lbs. superphosphate	5 lbs. ammonium sulfate 6 lbs. superphosphate 5 lbs. potassium chloride	6 lbs. superphosphate 5 lbs. potassium chloride

*An application of 2 tons of crushed limestone per acre was made to all plats in 1926.

Soil samples were taken for studies of the nutritive balance under which the plants were growing.

METHODS OF SAMPLING

Leaves.—About an hour before sunrise samples were obtained from bearing and non-bearing spurs on five different dates during the growing season of 1930. These dates were May 28, June 28, July 28, August 28, and September 28. Fifty leaves from bearing spurs and 50 from non-bearing spurs were collected from each tree, care being taken that all parts of the tree were represented. One-half of each sample was picked at an average height of 5 feet, and the other half from a height of 8 to 10 feet. The leaf samples were placed in air-tight jars and immediately sent to the laboratory at Pullman, Washington. Individual trees were sampled on the check and NP plats. A composite sample from three trees was made on each of the other plats. The green weight of the samples was obtained as quickly as possible after being received at the laboratory, and the samples were then placed in a drying oven at 60°C for 24 hours and again weighed to determine the dry weight. The dry samples were ground in a Wiley mill to pass through a 1-mm screen, bottled, and stored for analysis.

Soil.—Samples for nitrate nitrogen determinations were obtained at three periods throughout the growing season of 1930 as follows: April 15, May 15, and July 1. Composite samples of each plat were prepared by mixing samplings taken on the north, south, east, and west sides between the irrigation ditches at a distance of about 3 to 4 feet from the base of each record tree.

The organic residue on the surface of the soil was carefully removed, so the sample represented soil to a depth of 8 inches. The samples were air-dried on paper in the orchard to curtail further nitrification and shipped to the laboratory for analysis where they were passed through a 1-mm sieve and dried to constant weight. In July 1930, another set of composite soil samples for general use was taken from 16 holes evenly spaced around each record tree on each plat. Organic refuse on the surface was discarded, and the samples included the first foot of soil. They were shipped in a moist condition and were not allowed to dry out before being analyzed.

METHOD OF EXTRACTION

Nitrate nitrogen.—Forty grams of oven-dry soil were extracted with 100 cc of distilled water and 100 cc of lime water.

Acid-soluble.—Forty grams of moist soil were placed in a shaker bottle with 200 cc of 0.2 N HNO_3. A similar sample was used for soil moisture determination.

Electrodialysis.—One hundred grams of moist soil were immersed in 1 liter of water and filtered immediately to wash out the soluble salts. After washing, the soil was allowed to air dry.

METHODS OF ANALYSIS

Calcium.—Calcium and magnesium were determined by a modification of Burgess and Breazeale's (2) soap titration method.

Potassium.—The potassium in the ash of the leaves was determined by precipitation with sodium cobaltinitrate, according to the method suggested by Truog.[4] The platinic chloride method as given in the official methods (17) was used for the determination of the potassium in the electrodialysates and in all other cases, because the sodium present in these samples would have affected the determination by Truog's method.

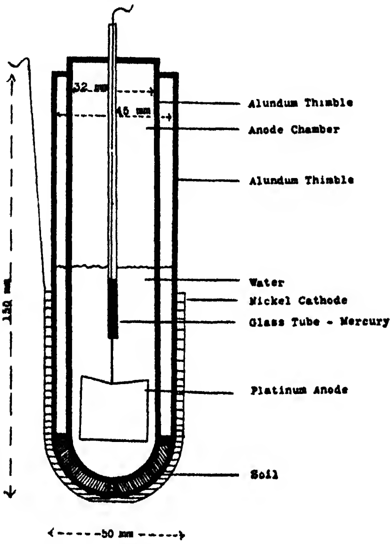

FIG. 2.—The electrodialyzer.

Sodium.—Sodium was obtained by difference, by subtracting the weight of the potassium salt from the weight of the combined chlorides.

Phosphorus.—This element was determined by a modification of the official methods (17). The phosphorus was allowed to precipitate by standing in the laboratory at room temperature for 20 hours. The precipitate was filtered through Gooch crucibles with asbestos pads, washed with a 2% solution of KNO_3, and titrated with standard alkali solution.

Total nitrogen.—A 0.5 gram sample of leaf tissue was used for total nitrogen determination by the Kjeldahl method (17).

Electrodialysis.—Ten-gram samples were weighed out and placed in a dialyzer. The dialyzer, a sketch of which is shown in Fig. 2, was constructed with two alundum thimbles, one 45 mm in diameter and the other 32 mm. A nickel screen was used as a cathode and a platinum leaf as an anode. The soil was placed between the two alundum thimbles and the small thimble was used for the anode chamber. The cathode surrounded the outside of the large thimble. The two thimbles and the electrodes were immersed in water in a 1-liter beaker which served as a cathode chamber. The distilled water entered through the small thimble and was drawn through the soil by electro-endosmosis into the area surrounding both thimbles where siphons were arranged to draw off the solution containing the bases. The voltage was held at 110 and the amperage at about 250 milliamperes. Approximately 2 liters of dialysate were collected from each sample. The dialysis was continuous for 12 hours. The total bases dialyzed from the soil were determined by titrating with 0.1 N HCl, using bromthymol blue as an indicator. The solution in the anion chamber was titrated with 0.1 N NaOH using the same indi-

[4]Truog, Emil. Private correspondence, 1930.

cator. After the total bases were titrated the solution was made strongly acid with HCl and evaporated to a small volume for analysis of the separate bases. The pH of the soil was determined after dialysis.

Nitrate nitrogen.—Nitrate nitrogen was determined by the official (17) phenoldisulfonic acid method.

Hydrogen-ion concentration.—All hydrogen-ion concentration determinations were made electrometrically with the quinhydrone electrode, 1 part of soil to 2 parts of water being used.

0.2 N HNO_3 extracts.—One hundred sixty cc of this extract were evaporated to dryness after a few drops of bromine water were added to destroy the organic matter. The residue was acidified with nitric acid and made up to a standard volume for analysis.

EXPERIMENTAL RESULTS WITH SOILS

EXTRACTION OF SOILS WITH WATER

The results of a qualitative examination of the water extract obtained when 1 liter of water was used to extract 100 grams of soil prior to the determination of dialysable substances are given in Table 2. There is some apparent relation between the quantities of water-soluble phosphorus and the fertilizer treatment as it is shown that more water-soluble phosphorus is present in the plats which have received superphosphate fertilizer than in those receiving none. There is no consistent relationship between the remaining water-soluble salts determined and the fertilizer treatments that the soils have received. For instance, several of the plats have received potassium fertilizers, but the untreated soil contained more water-soluble potassium.

TABLE 2.—*Qualitative analysis of water extracts and the pH of the soil samples and extract from the fertilizer plats in July, 1930.*

Plat	Qualitative analysis of water leaching					pH of soil		pH of water extract
	K	Ca	Cl	SO_4	PO_4	Before leaching	After leaching	
N	Med.	Med.	Low	High	Low	7.11	7.37	7.37
P	None	High	High	High	High	7.03	7.37	7.61
K	Low	Low	Low	None	Low	7.03	7.95	7.45
NK	Med.	Low	Low	Med.	Low	7.11	7.78	7.28
NP	None	High	High	Low	High	6.52	6.69	7.45
NPK	Med.	High	High	High	High	6.60	6.86	7.45
PK	Med.	Med.	Med.	Med.	High	7.87	8.21	7.53
Check	High	Low	Med.	Low	Med.	7.20	7.20	7.20

The pH values of the soil samples before and after extraction show a fairly consistent change toward a more alkaline reaction upon treatment with water. The soil from the check plat was an exception, since no change in reaction took place. The extracts were uniformly alkaline in reaction, so that it is somewhat difficult to account for the changes in the soil reactions. The results as a whole show that the water extracts are unreliable as indicators of soil conditions. Apparently some stronger solvent is needed to indicate accurately the fertility of the different soils.

Determination of electrical conductance of a sample of irrigation water taken at the orchard during the latter part of October showed that the water carried 68 p. p. m. of salt. It is assumed that this is approximately the maximum amount carried during the season because studies made in other investigations show that very little salt is carried by the water in spring and summer, but that it increases considerably during the late summer and autumn. This suggests that any changes brought about in the soil by this irrigation water would be mainly the result of leaching, since the concentration of salt in the irrigation water would generally be less than that of the soil solution itself.

EXTRACTION OF SOILS WITH 0.2 N NITRIC ACID

The 0.2 N nitric acid extractions of the soil from the various fertilizer plats were made in an attempt to obtain the adsorbed bases that are probably available to the plant as well as the plant food elements already dissolved in the soil solution.

Table 3 shows the quantities and milliequivalents of Ca, Mg, P_2O, K_2O, and Na_2O found in the soil, both results being expressed on the basis of 100 grams of dry soil. There was no relationship between the fertilizer treatments of the plats and the quantities of plant nutrients soluble in 0.2 N nitric acid. For instance, in connection with calcium, all those plats receiving annual treatments of superphosphate should contain more readily available calcium, because of the Ca added, but only one actually showed more calcium. Two treated plats contained more soluble magnesium than the check, while the remainder had smaller amounts. The phosphorus soluble in the check plat was exceeded by that obtained from the soils on plats receiving N, P, and K, while those plats receiving phosphorus in combination with some other element contained smaller amounts than the check. The same variability held for potassium, but the amounts of sodium in all of the treated plats were consistently less than that in the check plat. There was a tendency for phosphorus treatments, either alone or in combination, to reduce the soluble sodium content.

TABLE 3.—*Available nutrients of the soil in the fertilizer plats as determined by 0.2 N HNO_3 extractions.*

Plat	Ca, M. E. per 100 grams	Mg, M. E. per 100 grams	P, M. E. P_2O_5 per 100 grams	K, M. E. K_2O per 100 grams	Na, M. E. Na_2O per 100 grams
N.......	9.76	7.42	0.77	0.67	1.24
P.......	11.40	2.58	0.78	0.54	1.00
K.......	11.70	8.24	1.05	0.66	1.21
NK......	8.14	1.25	0.35	0.52	1.21
NP.....	6.80	5.67	0.16	0.51	0.81
NPK....	4.70	0.25	0.09	0.44	1.08
PK.....	8.70	1.64	0.19	0.29	0.27
Check..	10.00	6.16	0.58	0.36	1.63

Judging from these results, it appeared that the 0.2 N nitric acid extraction could not be used as a reliable indicator of the soil fertility conditions on these plats as affected by fertilizer applications, and some other methods were next investigated.

ELECTRODIALYSIS OF SOILS

It is apparently well established that hydrogen replaces the other bases in the soil complex during electrodialysis, and it was thought that such replacement might give results with these plat soils that would show their supplying capacities of nutrient bases. The results are shown in Table 4.

TABLE 4.—*Results of electrodialysis of soil samples from the fertilizer plats based on 100 grams of soil.*

Plat	pH of soil after dialysis	Some bases determined, M.E.	Hydroxide equivalent of total bases, M.E	Quantities of individual bases		
				Ca, M.E.	K, M.E.	Na, M.E.
N......	3.85	8.17	12.00	1.23	2.16	4.78
P......	3.38	11.97	15.70	1.19	1.89	8.89
K	3.55	7.35	14.10	1.33	1.79	4.23
NK.....	3.47	11.29	11.45	0.98	2.53	7.78
NP.....	3.72	8.52	12.20	0.89	1.88	5.75
NPK ..	3.47	8.11	14.10	1.04	1.61	5.46
PK.. ..	3.81	10.68	15.86	1.27	1.64	7.77
Check ..	3.13	6.98	10.35	1.12	1.51	4.35

The pH values of the plat soils after dialysis indicate a rather strong replacement of the nutrient bases by hydrogen, resulting in complexes which can supply a relatively strong concentration of acid ions. There is a range from 3.13 to 3.85 in pH values among the samples, but a generally high intensity of acidity did develop in all cases.

The total quantity of base replaced by hydrogen is in no way related to the final pH value of the soil, since the soil in which the lowest pH value was reached gave up 10.35 milliequivalents of bases, and a soil with nearly the highest pH value after dialysis gave up one-third more basic material. There does not seem to be any relation between the fertilizer treatments these soils have received and the total amount of dialysable bases they contain. Thus, the two soils receiving phosphorus and potassium fertilizers alone gave up just as much basic material as the soils receiving combinations of these two materials. On the other hand, there is a difference between the fertilized soils and the check, the latter having distinctly less basic nutrients in the dialysable form.

An examination of the amount of each individual base released by the different samples brings out some interesting comparisons. A notable thing is the preponderance of the alkali bases over the alkaline earths. It is almost certain that, even with the undetermined magnesium added to the calcium, the sodium and potassium would be the dominant bases, with the former present in the larger amount. Why there should be more sodium present in nearly all fertilized soils than in the check regardless of treatment is difficult to explain. The largest amount of dialysable potassium is present in the soil from the plat which received nitrogen and potassium fertilizer in combination. In several other plats also receiving potassium either

alone or in combinations, no particular increase over the minus potassium treatments was found. There is no relation between dialysable calcium and soil treatments. In fact some of the plats receiving calcium phosphate treatments yielded less replaceable calcium than the untreated soil.

Qualitative tests for carbonate, chloride, sulfate, and phosphate ions in the solution of the anion chamber after electrodialysis showed that only small quantities of these materials were present. Since the solution was acid, carbonate was found only in traces or not at all. The results obtained with the anions were so variable and the amounts present appeared to be so small that no quantitative determinations were made.

It is apparent, therefore, that the results obtained by this method showed no relationship between plat treatments and the mineral plant nutrients that might be available for plant growth. The lack of such definite relationship in this particular soil may be due to the relatively small amount of colloidal material present and the withdrawal of nutrients by the trees and cover crop.

SEASONAL VARIATION IN SOIL NITRATES

Soil samples were taken on April 15, May 15, and July 1, 1930, in order to determine the amount of nitrate nitrogen in the various plat soils on these dates. The results are given in Table 5. On April 15, plats NK, NP, and NPK were high in nitrate nitrogen, while the other plats showed considerable smaller amounts. The amount of nitrate in the soil agrees with the application of nitrogen to the plats when the nitrogen fertilizer was applied in combination with other materials. This suggests that the more balanced fertility of these plats was favorable for decomposition of organic matter and for promoting microbial activity and the accumulation of NO_3 early in the season.

TABLE 5.—*The amounts of nitrate nitrogen expressed as p.p.m. contained in the air-dry soil during 1930 on the dates indicated.**

Plat	April 15	May 15	July 1
N	8.6	25.0	4.0
P	3.8	3.1	2.9
K	4.9	5.5	7.6
NK	20.6	50.0	3.1
NP	16.1	33.3	5.8
NPK	20.8	33.3	3.8
PK	6.9	5.2	2.9
Check	4.8	6.6	2.9

*Fertilizers applied during month of December, 1929.

The growth of alfalfa did not seem to be increased to a noticeable degree by additions of nitrogen as judged by field observations, but the growth of grasses was increased considerably. Plats NPK, NP, and NK showed a rank growth of grass in 1930 and also the greatest nitrate nitrogen content in the soil throughout the season. The plat receiving nitrogen fertilizer alone had a poor cover crop and likewise

did not contain much nitrate nitrogen. Determinations on May 15 showed that the nitrate nitrogen in the N plat had increased considerably, but it had also increased in plats NK, NP, and NPK. In the PK, P, and K plats, as well as in the check plat, no accumulation of nitrogen occurred between April 15 and May 15. The amount of nitrate nitrogen was reduced to a low point on all of the plats on July

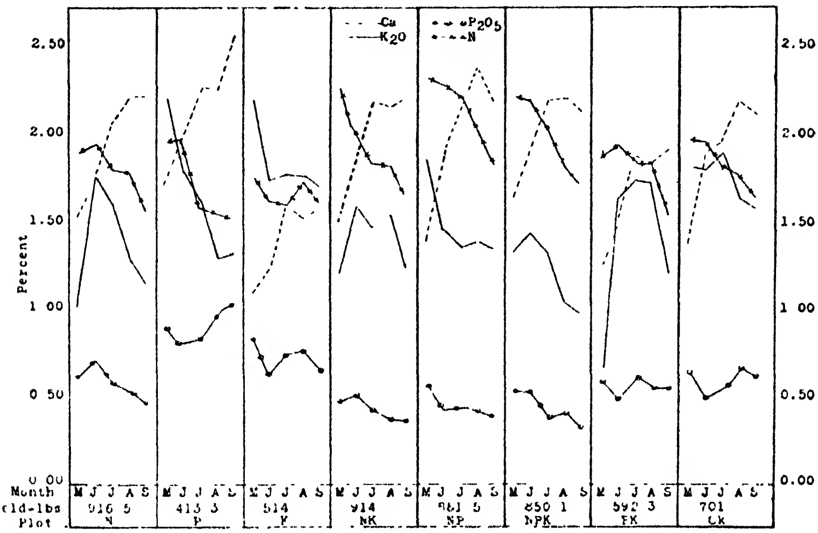

FIG. 3.—Percentage of Ca, K_2O, P_2O_5, and N in leaves from bearing spurs from the fertilizer plats May 28, June 28, July 28, August 28, and September 28, 1930.

1. Orchard fertilization experiments in Pennsylvania (19) showed that the cover crop is a fairly reliable index of the tree growth and the yield of fruit that may be expected 10 years later. It was found here that applications of nitrogen in combination with other elements increased the growth of the cover crop, later giving an increase in yield of fruit so that the cover crop thus provided a rough indication of the amount of nitrate nitrogen present in the soil.

EXPERIMENTAL RESULTS WITH PLANT MATERIALS

COMPOSITE LEAF ANALYSES

Soil analyses may give indications of the quantity of available plant nutrients, but it is more important to know what is being taken up by the tree. The results of any fertilizer treatment must be judged by the crop response it produces.

In this investigation, the leaves of the trees were sampled for chemical analyses in order to test the method employed by Lagatu and Maume for grapes on apple trees. Consequently, during 1930 leaf samples were taken at monthly intervals as described previously.

The results of the analyses for calcium, nitrogen, phosphorus as P_2O_5, and potassium as K_2O contained in leaves from bearing and non-bearing spurs from trees on the various fertilizer plats at five

points during the growing season are shown in Figs. 3 and 4. It may be noted that, in general, the percentage of P_2O_5 was noticeably high in the leaves of the P and K plats where a high percentage of P_2O_5 was found in the soil by nitric acid extraction. The percentage of nitrogen was lower in leaves of trees that did not receive an application of nitrogen fertilizer than was found in those treated with nitrogen

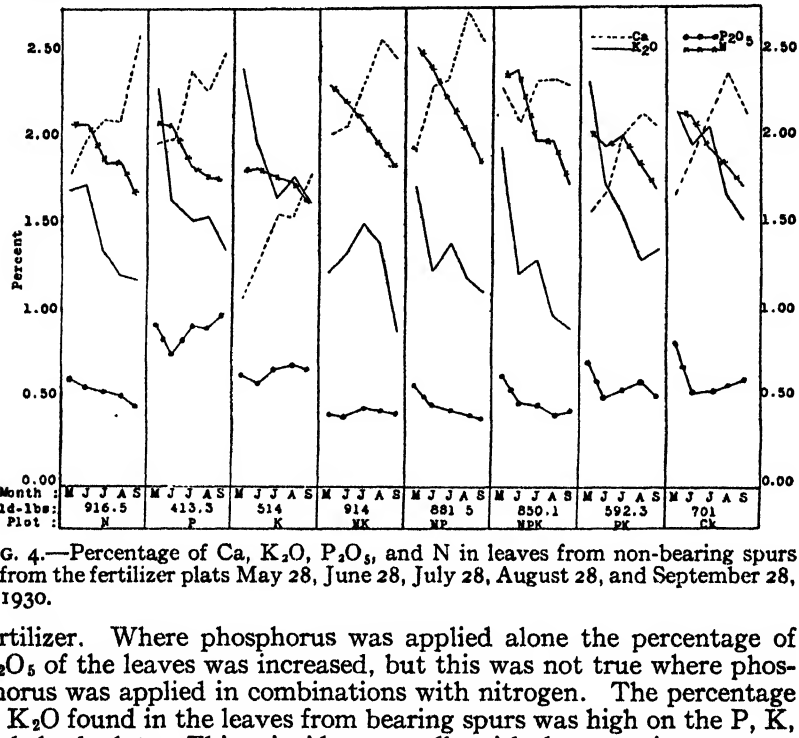

FIG. 4.—Percentage of Ca, K_2O, P_2O_5, and N in leaves from non-bearing spurs from the fertilizer plats May 28, June 28, July 28, August 28, and September 28, 1930.

fertilizer. Where phosphorus was applied alone the percentage of P_2O_5 of the leaves was increased, but this was not true where phosphorus was applied in combinations with nitrogen. The percentage of K_2O found in the leaves from bearing spurs was high on the P, K, and check plats. This coincides generally with the potassium content of the soil as indicated by 0.2 N nitric acid extractions. The N plat which has a slightly higher content of soluble K_2O than the check plat, according to this method, did not show it in the leaves. The quantity of calcium found in the leaves of the trees growing on the K plat was comparatively low, while the percentage in the soil was high as found by nitric acid extractions and replacement studies.

Cooper (4) has found that a high potassium content in the soil will reduce the amount of calcium in pasture grass and *vice versa*. Lagatu and Maume (13) have drawn the same conclusions from their work with grape leaves. The percentages of elements in leaves from non-bearing spurs, as shown in Fig. 4, bear similar relations to each other, but the amounts are higher than in leaves from bearing spurs in some cases and lower in others, probably due to differences arising from the growth of fruit on the latter.

It was observed that the leaves on the trees of the K plat were badly damaged by marginal burning similar to that described by Summers (20), and that the leaves were comparatively small. Sum-

mers believes that the characteristic browning of leaves suffering from scorch is an after effect which makes its appearance after the condition responsible for the scorch has passed and that the drying out of the leaf is caused by a sudden discontinuity in the transpiration stream. Since there were only small differences in the moisture content in the leaves from the K plat as compared with that in the leaves from trees of other plats, it is doubtful that the injury was due to water relations.

Davis (5) found that calcium omission caused leaf breakdown in the form of brown patches or blotches near the center or along the margin of the leaves; also, a highly significant negative correlation between K_2O and CaO was found in the ash of the shoots and leaves. It is possible that the large amount of K_2O present in the leaves reduced the CaO content, thus contributing to the leaf injury described. Similar leaf injury was noted by Mann (15) and was attributed to potassium deficiency. However, this deficiency is unlikely on the K plat because the leaves show a good supply of K_2O.

ANALYSES OF LEAVES FROM INDIVIDUAL TREES

The NP and check plats were chosen for leaf analysis of the individual trees because in 1929 the trees on the NP plat seemed to be responding very well to that fertilizer combination and the trees on the check plat appeared to be in the poorest condition. Three trees from each plat were utilized. The percentages of calcium, nitrogen, phosphorus as P_2O_5, and potassium as K_2O of leaves from bearing and non-bearing spurs from individual trees on the NP and check plats are graphically illustrated in Figs. 5 and 6.

Tree 1 on the check plat, which was located on the north side of the orchard (Fig. 1), was separated from tree 4 and tree 5. This tree was located close to an irrigation flume on a place that probably was rather difficult to water judging from the amount of undecomposed plant residues on the surface of the soil. This accumulated organic residue suggested slow decomposition of organic matter accompanied by slow nitrification, and probably for this reason the nitrogen content of the leaves of check tree 1 was low. As can be seen from Fig. 5, check tree 1 yielded 614 pounds of fruit in 1930 and only 238 pounds in 1929, which indicates a marked seasonal variation in production. Although there were no great differences in the percentage of plant food elements of the leaves on check trees 4 and 5, the percentage of phosphorus of the leaves on check tree 5 was lower than that in the leaves on check tree 4, and this was accompanied by a decrease in yield. Lagatu and Maume (14) state that the yield of grapes was reduced when the potassium was so deficient that it did not surpass the nitrogen.

This potassium relation does not seem to be true for apple production, because in this experiment the yield was reduced when the amount of potassium exceeded the nitrogen. Cooper (4) found from investigation on pasture grasses that there was a correlation between the absorption of potassium and phosphorus because both of these elements were found in rather large amounts at the same time.

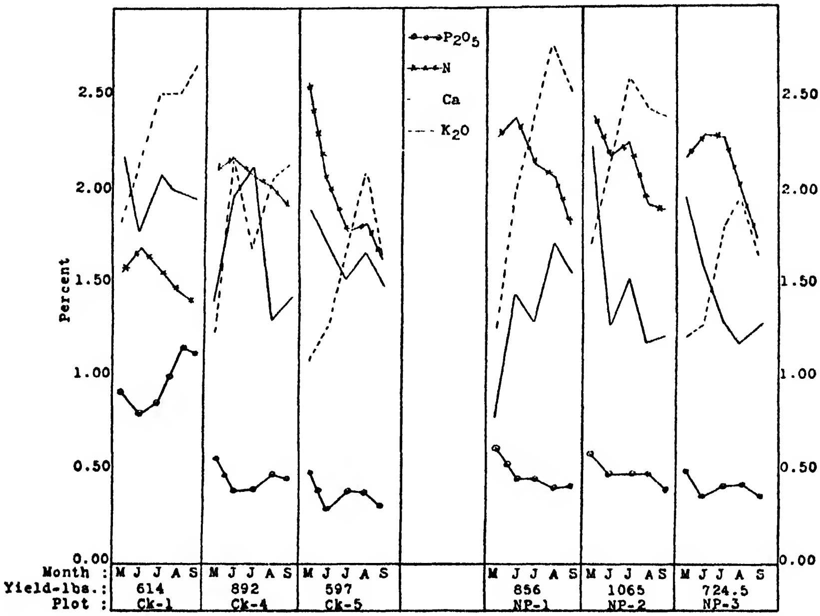

FIG. 5.—Percentage of Ca, K_2O, P_2O_5, and N in leaves from bearing spurs from individual trees on check and NP plats on May 28, June 28, July 28, August 28, and September 28, 1930.

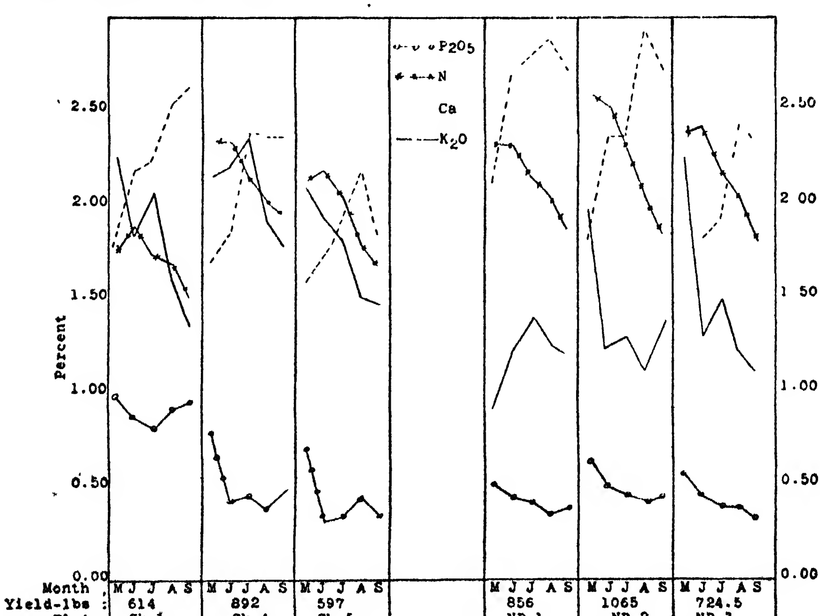

FIG. 6.—Percentage of Ca, K_2O, P_2O_5, and N in leaves from non-bearing spurs from individual trees on the check and NP plats on May 28, June 28, July 28, August 28, and September 28, 1930.

The curves representing the nutrient elements of the leaves from bearing spurs of individual trees on the NP plat run in a quite similar direction. The yield for trees 2 and 3 on plat NP showed a tendency toward alternate bearing. In 1929, tree 2 yielded 584 pounds of fruit and 1,065 pounds in 1930. Tree 3 yielded 945 pounds in 1929 and 724 pounds in 1930. These data suggest that it is possible for trees to develop individual yield characteristics through environmental conditions not necessarily associated with the plant nutrient supply of the soil.

In order to compare the ratio of plant foods in the leaves from bearing spurs of individual apple trees from the check and NP plats with the ratio found by Lagatu and Maume, the average nitrogen, K_2O, and P_2O_5 content for the season of 1930 was calculated and is shown in Table 6.

TABLE 6.—*The average ratio of percentage of N, K_2O, and P_2O_5 in the leaves from bearing spurs of individual trees on plats NP and check, 1930.*

Tree	Average percentage of			Fruit, lbs.
	N	K_2O	P_2O_5	
NP-1	2.15	1.37	0.48	856
NP-2	2.15	1.51	0.49	1,065
NP-3	2.10	1.49	0.42	724.5
Check—1	1.54	2.00	0.98	614
Check—4	2.06	1.65	0.47	892
Check—5	1.98	1.67	0.37	597
Lagatu and Maume	1.78	1.66	0.48	Best yield

Tree 2 on the NP plat produced the greatest weight of apples. Apparently the deviation of the ratio in trees 1 and 3 in this plat from that found in the leaves of tree 2 reduced the yield of the other trees, although a natural seasonal variation may partly account for the differences in yield. With respect to the P_2O_5 content of the leaves, a higher or lower amount than 0.49% reduced the yield materially.

It is interesting to note the close relationship between the ratios of these elements in apples and in grapes, the apple tree leaves having, however, a somewhat higher nitrogen content, on the average.

The percentage of nutrient elements in the leaves from non-bearing and bearing spurs of individual trees on the NP and check plats are higher in some cases and lower in others.

YIELD OF FRUIT

The average yield of fruit in pounds, the average number of apples per tree, and the differences in yield compared with the check are shown in Table 7. It will be recalled that plats NK and NP were not fertilized until 1928 and that the check plat consisted of only two trees in 1927 and 1928. In 1927, plats N and PK gave a larger yield than the check plat and plats P and NPK gave smaller ones. The

TABLE 7.—*The average yield of apples and the number of apples per tree from the fertilizer plats for four years.*

Plat	1927		1928			1929			1930		
	Weight. lbs.	Difference over check, lbs.	Weight, lbs.	Difference over check, lbs.	No. of apples	Weight, lbs.	Difference over check, lbs.	No. of apples	Weight, lbs.	Difference over check, lbs.	No. of apples
N	568.3	+ 72.3	420	— 72	1,701	629.3	+131.7	2,104	916.5	+215.5	3,464
P	351.6	—144.4	358	—134	1,533	492.8	— 4.8	2,019	413.3	—288.3	1,651
K	470.3	+ 25.7	346	—146	1,484	663.5	+165.9	2,635	514.0	—187.0	2,224
NK	——		301	—191	1,005	755.8	+258.2	2,603	914.1	+213.1	3,081
NP	——		403	— 89	1,589	794.3	+296.7	2,756	881.8	+180.8	3,155
NPK	361.6	—134.4	388	—104	1,448	661.3	+163.7	2,343	850.1	+149.1	2,926
PK	630.3	+134.3	388	—104	1,551	678.8	+181.2	2,539	592.3	—108.7	2,392
Ck	496.0*		492*		1,911*	497.6		1,707	701.0		2,533

*Result from 2 trees only.

yields at this time depended upon the season and general orchard practices prior to fertilization. In 1928, the yield of all the plats was lower than that of the check. The PK and N plats showed a considerably reduced yield from the previous year which suggested alternate bearing characteristics of the trees. In 1929 all the plats except that receiving phosphorus showed an increase in yield over the check. The yields of plats NPK, NP, and NK showed marked increase over those of the first 2 years. In 1930, plats P, K, and PK showed a decreased yield over that of 1929 and yielded less than the check plat in spite of the fact that it was a very favorable season for apples.

Plats receiving NK, NP, NPK, and N have shown a gradual and consistent increase in yield since 1928, which indicates that the fertilizers have been taking effect. It appears that, where nitrogen has been applied either alone or in combination with other fertilizers, the soil conditions have been improved and the yield of apples has increased steadily.

DISCUSSION

The Ephrata fine sand was formed under semi-arid conditions with insufficient rainfall to leach entirely from the soil the soluble materials formed by natural weathering processes. Soils formed under these conditions usually are of a coarse texture, and the colloidal fraction is very small. As weathering continues under the application of irrigation water, it is to be expected that the colloidal fraction will increase slightly in amount. Parker and Pate (18) and Gedroiz (7) have shown that exchange reactions take place only in the colloidal fraction. Because of the coarse texture and manner of formation of the Ephrata fine sand, the total exchange capacity of the fertilizer plats would not be expected to be large.

These considerations lead to the conclusion that the soil dealt with cannot fix fertilizer elements by exchange reactions to any appreciable degree and for this reason residual effects of several years of fertilization may be expected to be small. Fertilizers added to this soil must be used the same season that they are applied, otherwise they will gradually be lost in seepage waters.

These conditions may account in part for the lack of consistent results obtained with the several soil analyses, and to a somewhat less degree perhaps they may account for the great variability in yields on adjacent trees.

An attempt to correlate the results from soil analyses with the yield from the trees showed that there was no continuously clean-cut relation between them.

Comparisons of total quantity of nitrate nitrogen found in the soil of the plats on April 15, May 15, and July 1 show that where the nitrates were high the yield was consistently high. It appears that the best method of estimating the fertility at the present time would be to determine nitrates in the soil. The relation of nitrogen fertilizers to yield is shown best in tabular form as presented in Table 8.

As can be seen in this table, K_2O does not seem to be related to the yield and the same is apparently true of calcium. A low content of

P_2O_5 in the leaves seems to be conducive to a larger yield than a high P_2O_5 content. Where nitrogen has been added to the soil, the nitrogen content of the leaves has been increased above the check except in one plat. This increase is probably due to the setting up of a

TABLE 8.—*Comparison of yield with the sum of the percentages of K_2O, Ca, P_2O_5, and N found in the leaves from bearing spurs from the five monthly determinations.*

Plat	N	P	K	NK	NP	NPK	PK	Check
K_2O......	6.83	8.30	9.30	7.15	7.41	6.14	7.02	8.77
Ca..	9.93	10.87	7.10	9.97	10.00	10.15	8.34	9.54
P_2O_5.......	2.92	4.59	3.71	2.22	2.38	2.13	2.80	3.04
N...	9.09	8.75	8.40	9.75	10.70	10.00	9.11	9.18
Yield, lbs...	916.5	413.3	514.0	914.0	881.5	850.1	592.3	701.0
Difference.. from check, lbs........	215.5	—287.7	—187.0	213.0	180.5	149.1	—108.7	

physiological ratio that is better adapted to the production of fruit. Therefore, it can be concluded that nitrogen is the only element added by fertilizers that distinctly increases the yield in this orchard at the present time and that the other nutrient elements added are supplementary in their effect. With the exception of calcium, the amount of plant nutrients found in the soil by nitric acid extraction is reflected in the content of the leaves.

In comparing the two plats that gave the greatest yield in 1930, namely, N and NK, the ratio of nitrogen, K_2O, and P_2O_5 was very similar, except that the nitrogen content is a little higher and the P_2O_5 content a little lower in NK plat. It must be mentioned that the quality of fruit was not considered in this paper and more work will be required to correlate quality of fruit with the correct physiological ratio of plant nutrients of the leaves. If future investigation will bear out the relationship reported in this paper in other types of soil as well as in Ephrata fine sand, foliar diagnosis of apple trees could be used as a guide to orchard fertilization.

SUMMARY

1. The object of these investigations was to attempt to discover the effect of various fertilizer treatments on the absorbing complex of the soil and its relation to tree response and yield of fruit from Jonathan apple trees growing on irrigated Ephrata fine sand in the Wenatchee orchard district.

2. Water extraction of soils treated with different fertilizers gave no reliable indications of relative productivity.

3. Extraction of the plat soils with 0.2 N nitric acid gave results which did not show the fertility conditions of these soils as affected by the fertilizer applications.

4. Electrodialysis of the soils was apparently of no perceptible value in estimating the productivity of these plats. The absence of

correlations is attributed to the character of the soil in that it does not fix fertilizer elements to any appreciable degree.

5. The amount of nitrate nitrogen contained in the plat soils during the first half of the growing season was rather closely correlated with the actual production of fruit. After July 1, however, only negligible amounts were found.

6. The H-ion concentration of the various plat soils showed that combinations of nitrogen and phosphorus and nitrogen, phosphorus, and potassium increased the acidity of the soil.

7. Apple leaves from trees on fertilizer plats were analyzed each month for 5 months for calcium, nitrogen, phosphorus as P_2O_5, and potassium as K_2O. The variation in percentage of each of the above-mentioned elements when shown graphically for the season reveals a tendency for the elements to be in a definite ratio to each other when production is good. Plats producing leaves with a relatively low percentage of P_2O_5 and a high percentage of nitrogen gave an increased yield. The most favorable ratios found for apple tree leaves are quite similar to those reported by Lagatu and Maume for grapes.

8. Yields from the fertilizer plats show that where nitrogen has been applied alone or in combination with other fertilizers, yields have been increased. Plats N, NK, NP, and NPK have shown a steady increase in yield since 1928. This condition is reflected in the higher nitrogen content of the leaves produced on these plats.

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THE SOIL EROSION PROBLEM IN NEW JERSEY[1]

LINWOOD L. LEE[2]

New Jersey is a relatively small state, lying between the parallels of 38°55'40" and 41°21'22.6" north latitude and the meridians of 73°53'39" and 75°35'00" west longitude. The state of New York adjoins on the north, on the east is the Hudson River, New York Bay, and the Atlantic Ocean, on the south the Atlantic Ocean and Delaware Bay, and on the west the Delaware River. It is therefore surrounded on three sides by water. The state of Delaware lies adjacent to the southwest and Pennsylvania to the west.

New Jersey has an extreme length of only 166 miles and in its northwest part, extending from Trenton to Raritan Bay, it is but 32 miles wide. A maximum width of 65 miles is attained between the Delaware and Hudson Rivers in the northern portion. The state has a land area of 7,514 square miles with 710 square miles of water—bays, harbors, lakes, etc., some salt, some fresh. Many glacial fresh water lakes are found in the northern part.

GEOGRAPHIC PROVINCES AND UNDERLYING ROCKS

New Jersey lies in four geographic provinces and all seven soil provinces. The geographic provinces are the Appalachian Valley, the Appalachian Highlands, the Piedmont Plateau, and the Coastal Plain (Fig. 1).

The Appalachian Valley has an area of 635 square miles, about one-twelfth of the state. It is about 40 miles long and 12 miles wide.

[1]Contribution from the Division of Soils and Crops, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Also presented at the annual meeting of the Society held in Washington, D. C., November 18, 1932. Received for publication December 19, 1932.

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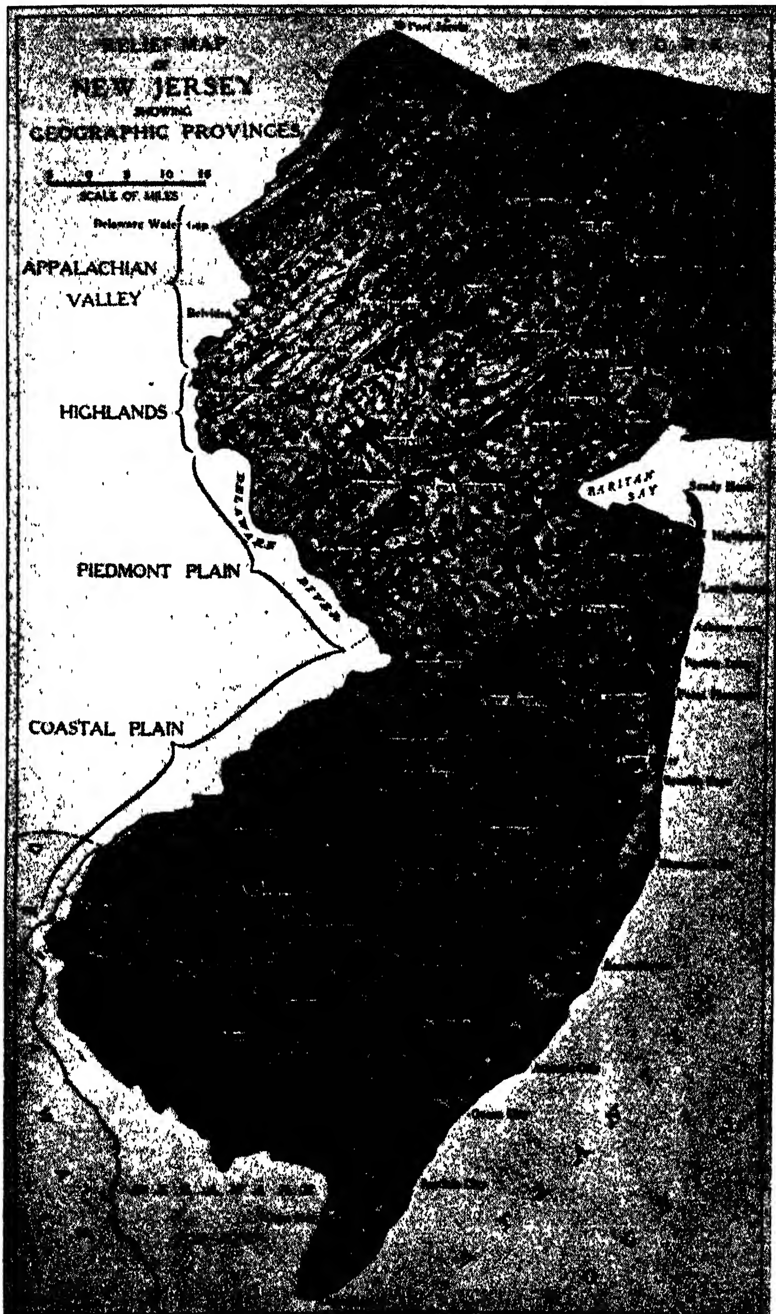


Courtesy of the New Jersey Dept. of Agriculture.

FIG. 1.—The geographic provinces of New Jersey.

The eastern part is occupied by the broad Kittatinny Valley and the western part by the narrow valley of the Delaware, the two being separated by the even-crested ridge of Kittatinny Mountain, an extension of the Blue Ridge. The plains and valley lands are from 400 to 600 feet above sea level and the hills and ridges reach a maximum height of about 1,000 feet. The crest of Kittatinny Mountain reaches an elevation of 1,804 feet at High Point, the highest elevation in the state.

The underlying rocks consist of sandstones, shales, and limestones. All of this province has been glaciated.

The Appalachian Highlands form a belt 10 to 25 miles wide extending across the state in a northeasterly, southwesterly direction (Fig. 1). They have an area of 900 square miles or about one-eighth of the state, and an average elevation of about 1,000 feet. In general, the Highlands consist of several broad, rounded, or flat-topped ridges rising 400 to 600 feet above the lowlands on either side and separated from each other by deep and generally narrow valleys.

The region is underlain by gneiss, sandstones, shales, conglomerates, and limestone. Most of it has been glaciated.

The *Piedmont Plateau* adjoins on the southeast. It is chiefly a lowland of gently rounded hills separated by wide valleys. The general elevation is from 400 feet to sea level. There are some ridges. The Watchung Mountains are the highest of these, with a maximum elevation of 879 feet. Sourland Mountain, lying to the southwest, is 563 feet at its highest point.

The underlying rocks consist principally of red sandstone and shale, some igneous rocks (trap), and argillite. The northeastern half has been glaciated.

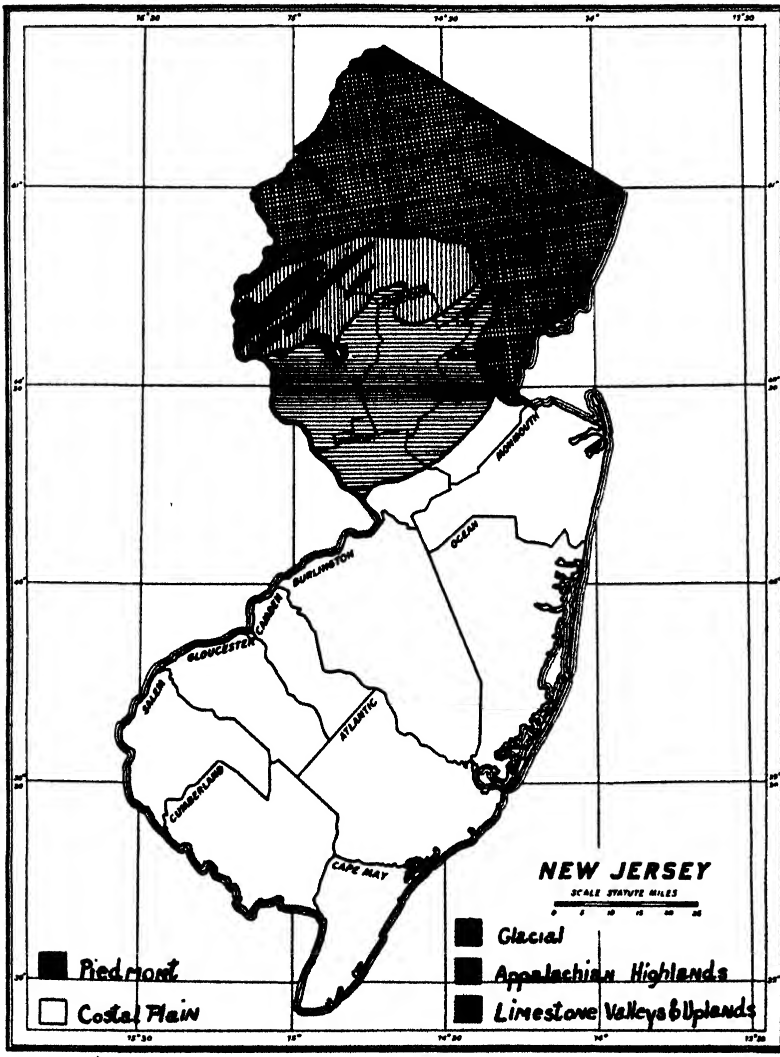
The *Coastal Plain* lies to the southeast. It comprises about three-fifths of the entire area of the state. Its surface in general is a dissected plain that rises gradually from sea level at the coast to about 300 feet in the northern portion. The region is underlain entirely by unconsolidated layers of gravel, sand, silt, and clay. A large part is forested.

SOIL PROVINCES

All seven soil provinces are represented in New Jersey (Fig. 2). According to the more recent grouping of the United States by Dr. Marbut, all of the state has been classified in sub-group II of Major Group A, that is, soils formed in the mid-latitude belt of the United States extending from the Atlantic seaboard to the prairies of Illinois, Iowa, and Minnesota. These soils are designated as podsolic soils of the brown forest soil group.

TOPOGRAPHY

In the Appalachian Valley, the principal topographic features are the even-crested Kittatinny Mountains with rather gentle slopes for the most part forested and the rolling topography of the Kittatinny Valley underlain with shale and largely cleared of its virgin forest growth. The mountain slopes in the Highlands are more abrupt and the valleys less rolling. The general topography of the Piedmont is rolling with many rather steep slopes, while the Coastal Plain is rather flat with occasional gentle to somewhat steep slopes.



Courtesy of the New Jersey Dept. of Agriculture.

FIG. 2.—The soil provinces of New Jersey. Two soil provinces are not shown on the map. One of these is the Glacial Lake and River Terrace Province, the soils of which occur locally in the glaciated area. They are derived from stratified glacial deposits, including those formed by glacier-fed streams and along the shores of old lakes. The other is the River Flood Plains Province which includes those soils transported and deposited by streams. They occur as narrow irregular areas bordering practically all streams.

CLIMATE

New Jersey has a relatively moderate climate with extended extremes of heat or cold rare. More snow occurs in the northern portion than in the southern section (Table 1).

TABLE 1.—*Comparative annual meteorological data for the state.*

Year	Temperature, °F			Average precipitation, inches	Average snowfall, inches
	Mean	Highest	Lowest		
1885	50.5	100	— 2	37.87	——
1886	50.2	98	—10	46.54	——
1887	51.1	102	— 6	47.66	——
1888	50.0	99	—12	52.20	——
1889	52.8	95	— 3	63.33	——
1890	53.2	101	0	49.34	——
1891	53.2	102	1	47.98	——
1892	51.4	105	— 6	42.04	——
1893	50.8	103	—21	47.90	——
1894	53.0	106	—11	47.37	——
1895	51.7	109	—12	37.29	25.7
1896	51.7	105	—15	42.51	39.5
1897	52.0	102	— 6	51.72	25.8
1898	53.2	107	—15	52.35	34.3
1899	52.1	103	—21	45.84	44.3
1900	53.8	104	— 9	42.71	23.3
1901	51.4	107	— 8	51.80	14.1
1902	51.8	100	—11	59.44	40.1
1903	51.7	100	—16	56.25	22.3
1904	49.3	100	—34	43.78	48.5
1905	51.3	102	—18	42.06	32.9
1906	52.8	98	—15	46.38	23.4
1907	50.4	96	—22	51.65	54.1
1908	52.6	106	—17	42.58	35.3
1909	52.0	100	—15	40.86	29.9
1910	52.0	99	—15	39.73	33.3
1911	52.6	104	—12	50.36	30.0
1912	51.3	100	—32	46.61	35.1
1913	54.2	100	—11	46.99	5.2
1914	51.4	99	—12	39.23	41.1
1915	52.5	98	— 3	47.37	39.4
1916	51.2	100	—18	38.17	49.6
1917	49.6	104	—21	40.80	40.4
1918	51.2	108	—16	37.65	25.3
1919	52.5	103	—12	52.10	10.9
1920	51.2	98	—17	51.87	33.4
1921	54.1	100	— 5	38.16	23.0
1922	52.6	98	—11	41.57	30.8
1923	51.9	106	—14	40.38	39.8
1924	50.7	102	— 6	44.17	24.3
1925	52.1	103	—20	42.15	26.8
1926	50.0	105	—11	44.41	32.2
1927	52.0	99	—12	49.68	13.7
1928	52.0	99	—15	46.22	21.5
1929	52.3	102	— 9	42.96	16.0
1930	52.8	105	—14	35.28	15.6
1931	54.4	102	— 9	37.07	8.6

The annual rainfall is exceptionally uniform, the average monthly distribution being close to 4 inches. Torrential thunder storms are common from June to September.

SOILS

A detailed soil survey of all of New Jersey has been completed and the results published. The data show that it is a state in which the soils are extremely diversified. There are 174 soil types embraced in 51 soil series and ranging in extent from 480,320 acres of Sassafras sand to 128 acres of the silty phase of Gloucester loam. The texture of the surface soils and other horizons of the soil profile also occur over a great range, but for the most part relatively light to medium textured surface soils predominate. In round numbers there are approximately 700,000 acres of sands, 170,000 acres of loamy sands, 840,000 acres of sandy loams, and 1,130,000 acres of loams. Of the heavier textured surface soils there occur 250,000 acres of silt loams, 10,500 acres of silty clay loams, 3,500 acres of clay loams, and 700 acres of clay (Table 2). Most of the loams and heavier soils are found in the northern and central part of the state, while the lighter more sandy soils predominate in the southern portion.

THE SOIL EROSION PROBLEM IN NEW JERSEY

Much land in New Jersey is suffering severely from all three types of erosion—gulley, sheet, and wind—to an extent heretofore unrecognized. In degree, it is directly influenced by plant cover, methods of cultivation, degree of slope, and soil type.

EROSION IN THE APPALACHIAN VALLEY

Much of the land in this province still remains in forest and, therefore, is protected to a marked degree from erosion. Most of the valleys consisting of Dover, Hoosic, and Dutchess soils have been cleared and are now utilized for agriculture. General farm crops, such as corn, wheat, rye, oats, timothy, clover, and alfalfa, are grown in rotation so that for considerable periods the land remains in sod. This practice of rotation has materially assisted in controlling erosion, but most of the land is rolling and therefore erodes badly when cultivated to corn. Gulley and sheet erosion are therefore common especially on the Dutchess soils.

THE HIGHLANDS

The more steep and abrupt slopes of the Highlands are underlain by the Chester and Gloucester soils. These are for the most part wooded and therefore protected from erosion, except on the lower, more gentle slopes, which have been cleared and are now utilized for the production of general farm crops. On such situations, gulley and sheet erosion is serious but would be much more so were not crop rotation the general practice.

In the valleys the Washington, Hagerstown, Dover, and Hoosic soils predominate and erosion is severe on slopes of 2% or more.

THE PIEDMONT PLAIN

The principal soils of the Piedmont in New Jersey belong to the Montalto, Washington, Penn, and Lansdale series. The Montalto

soils derived from trap occur on relatively high elevations with rather steep slopes for the most part forested and therefore partially protected from erosion. Most of the virgin forest growth has been removed from the Washington, Penn, and Lansdale soils for a century

TABLE 2.—*Extent in acres of agricultural soils of New Jersey according to textural classification.*

	Well drained			Poorly drained		
	South Jersey	North Jersey	Entire state	South Jersey	North Jersey	Entire state
			Sands			
Gravelly	1,152	——	1 152	——	——	——
Coarse	30,440	——	30,440	——	——	——
Medium	542,848	384	543,232	94 784	——	94,784
Fine	38,336	2,688	41,024	5,120	——	5,120
Totals	612,776	3,072	615,848	99,904	——	99,904
			Loamy Sands			
Coarse	8,640	——	8,640	——	——	——
Medium	114,368	6,464	120,832	41,216	——	41,216
Totals	123,008	6,464	129,472	41,216	——	41,216
			Sandy Loams			
Stony	——	13,184	13,184	——	——	——
Gravelly	209,034	4,480	213,514	——	——	——
Gravelly fine	——	1,280	1,280	——	——	——
Coarse	15,424	——	15,424	——	——	——
Medium	281,080	28,928	310,008	112,832	——	112,832
Fine	148,008	17,728	165,736	8,320	——	8,320
Totals	653,546	65,600	719,146	121,152	——	121,152
			Loams			
Stony	——	217,408	217,408	——	5,376	5,376
Gravelly	2,304	255,744	258,048	——	——	——
Shale	——	161,792	161,792	——	——	——
Loam	226,850	181,440	408,290	83,576	38,144	121,720
Totals	229,154	816,384	1,045,538	83,576	43,520	127,096
			Silt Loams			
——	3,264	223,004	226,268	24,424	101,092	125,516
			Silty Clay Loams			
——	——	——	——	10,580	28,096	38,676
			Clay Loams			
——	2,816	——	2,816	832	——	832
			Clay			
——	704	——	704	——	——	——

or more and they occur for the most part on rolling topography. General farm crops are grown in rotation, but sheet and gulley erosion is most severe and widespread. Fully 80% of the cleared area of the Penn and Lansdale soils are suffering from sheet erosion resulting in the loss of vast quantities of surface soil and in many places the sub-

soil is exposed. In many other places sheet and gulley erosion are so severe that bed rock is exposed over extensive areas either on the surface or 2 or 3 inches below.

On the Washington soils of the Piedmont, gulley and sheet erosion have actually destroyed many thousands of acres of formally valuable land. In one area in the southwestern part of this province over 10 feet of soil has been eroded away (Fig. 3) and in the same vicinity one gulley moved 30 feet on a 6 to 7% grade between the crop year 1931 and 1932. In this district the Washington soils, which owe their origin to glacial drift, overlie the Triassic red sandstone and shale from which the inferior Penn soils are formed so that in many places all, or a large part, of the glacial drift has been removed by erosion so that what was formally excellent and valuable Washington soils have degraded into a very poor eroded type of Penn. In one location more than 2,000 acres in an almost solid block has undergone such degradation and the land now stands entirely abandoned for agriculture.

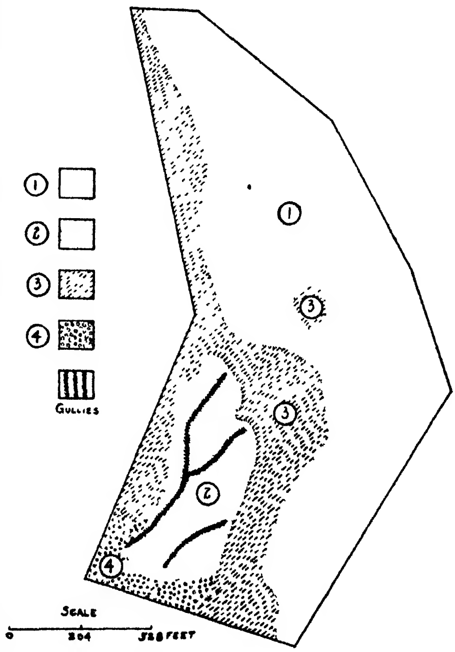


FIG. 3.—Soil impairment on slight slopes of not more than 5%. Washington loam; Piedmont, New Jersey. 1, Surface soil all eroded away exposing stiff, plastic clay; 2, surface soil 0 to 4 inches in depth; 3, surface soil 5 inches deep; 4, surface soil 20 inches deep (colluvial materials). Surveyed by Linwood L. Lee, 1932.

THE COASTAL PLAIN

The Coastal Plain of New Jersey may be conveniently divided into two broad divisions, the western two-fifths being designated as the Heavy Belt and the eastern three-fifths as the Light Sandy Belt. The latter belt has a level flat topography and is almost entirely forested so that in spite of the very sandy character of the soil erosion is not serious. The Heavy Coastal Plain Belt, however, is almost entirely cleared of its virgin timber and utilized largely in the intensive production of potatoes, fruit, corn, and vegetable crops. Such a cropping system does not lend itself to rotation. Generally, the topography is quite level to gently sloping and locally rolling. The soils of the Sassafras and Collington series predominate and occur for the most part as loams and sandy loams. In this belt sheet and gulley erosion are depleting vast areas of the surface soil. There is scarcely any cultivated sloping land upon which the subsoil is not exposed and erosion is very serious even on slopes of less than 1%.

There are many thousands of acres of apples and peach orchards in this district in which clean methods of cultivation are in practice. The tracks of spraying apparatus constantly keep open old and open up new courses for water run-off so that gulleys are a common occurrence between the rows of fruit. They vary in depth from a few inches to as much as 3 feet and in places are so widespread that trees 12 to 20 years old find themselves with roots exposed and isolated on "islands" 2 or 3 feet above the surrounding ground level. Erosion of this extent occurs on slopes of 4 to 10%. Many orchards on sites of this type are highly unsuccessful and will probably soon be abandoned. Serious erosion, however, occurs frequently in orchards with a slope of less than 1%.

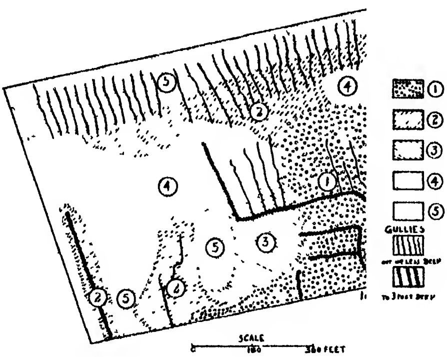


FIG. 4.—Soil impairment in orchards by erosion. Collington sandy loam, deep phase; Coastal Plain, New Jersey. 1, Surface soil entirely removed, clayey subsoil exposed; 2, depth of surface soil 1 to 2 inches; 3, depth of surface soil 2 to 5 inches; 4, depth of surface soil 5 to 6 inches; and 5, depth of surface soil normal or better, 6 inches plus. Surveyed by Linwood L. Lee, 1932

A detailed erosion survey in a 6-acre, 20-year orchard of Rome and York apples located on the deep phase of the Collington sandy loam receiving clean cultivation and having a slope of from 1 to 5% showed that in 18.8% of this orchard all the surface soil had been removed, 26.0% of the soil showing a surface horizon from 1 to 2 inches thick, 6.2% a surface depth of 2 to 5 inches, and 28.2% a thickness of 5 to 6 inches. The normal surface soil depth of 6 inches or more was found only in 20.8% of the orchard, indicating that about 80% had suffered erosion to some degree, and that in about 45% of it the surface soil had been practically removed. Gullies occurred between practically every row of trees on slopes greater than 3% and in places these attained a depth of 2 to 3 feet (Fig. 4).

It is of the utmost importance that remedial measures be taken without delay in order to avoid further damage and prevent an already serious soil condition from becoming even more difficult to control. There are no extensive detailed data showing the extent of the scourge of soil erosion in New Jersey, but the preliminary surveys upon which this paper is based have conclusively brought to light that the damage is widespread and of the utmost seriousness. This condition must be met by an educational and research program, having as an aim the working out of efficient and economical control methods best fitted to local topographic, cultural, and soil conditions.

THE AVAILABILITY AND DOWNWARD MOVEMENT OF ROCK PHOSPHATE IN ILLINOIS SOILS WHEN USED LIBERALLY FOR 25 TO 30 YEARS AND INFLUENCE OF THE TREATMENT ON AVAILABLE POTASH AND TOTAL NITROGEN[1]

A. U. Thor[2]

Very few investigations have been made relative to the downward movement and accumulation of phosphorus below the plowed layer in corn belt soils when rock phosphate has been applied for a considerable number of years. For this reason, and also because some corn belt farmers have reported marked increases in crop yields on soils which have received repeated applications of rock phosphate, it seemed desirable to make this special study of the soils of three well-known corn belt farms with particular emphasis on the downward movement of the rock phosphate as well as its availability and influence on available potassium and total nitrogen.

Previous investigations indicate that usually the greater portion of the phosphorus applied as fertilizer remains in the surface soil. Dyer (2)[3] states that long-continued use of manure resulted in a slight but appreciable downward movement of phosphorus into the second and third 9-inch depths. He reports a similar movement when superphosphate was accompanied by dressings of potassium, sodium, and magnesium salts.

Waynick and Leavitt (16) applied "Ammo-Phos" to sandy, adobe, and clay citrus grove soils and found that a slight descent of the phosphorus occurred to a depth of 12 to 34 inches, depending on the rate of application.

Crawley (1) found that large applications of soluble phosphate to Hawaiian soils, followed by immediate irrigation, left practically all of the phosphorus within 6 inches of the surface. When irrigation was deferred for 15 hours, practically all of the phosphorus was found in the first 3 inches of the soil.

Stephenson and Chapman (11), in a recent study of the soils of citrus groves which had received very heavy applications of superphosphate and manure for several years, found a downward movement of phosphorus in the lighter soils to a depth of 24 to 36 inches.

Midgley (9) found that when superphosphate is applied as a surface dressing to pastures, practically all of the phosphorus is found within the surface inch of soil 6 months after application.

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wisc. Part of a thesis submitted in partial fulfillment of the requirements for the degree of master of science and published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication January 3, 1933.

[2]Formerly Assistant, Department of Agronomy, University of Illinois; now student, University of Wisconsin. The writer is indebted to Professor E. Truog, under whose direction this investigation was conducted, for his helpful suggestions and criticisms; to John C. Mies and Frank I. Mann for furnishing crop yield data and for the privilege of sampling their fields; and to Professor H. J. Snider for securing samples of soil from the Hopkins' "Poorland Farm."

[3]Reference by number is to "Literature Cited," p. 673.

DESCRIPTION AND HISTORY OF THE FARMS STUDIED

Soil samples were secured from the John Mies and Frank I. Mann farms and the Hopkins' "Poorland Farm." The brown silt loams of the Mies and Mann farms are typical prairie soils of the corn belt area. The soil of the Hopkins' "Poorland Farm" is a gray silt loam which is quite different in texture and drainage from the usual corn belt soil. The classification of these soils is given according to the county soil survey reports (5, 6, 8) and direct information from Dr. R. S. Smith and Professor E. A. Norton, University of Illinois.

Mies farm.—This farm is located in Livingston County in the north central part of Illinois. It consists of level, well-drained prairie soil, mapped as brown silt loam (Brenton silt loam, sandy phase) which is underlain with a coarse sand at a depth of 36 to 40 inches. The organic matter content of the soil is relatively high, surface and subsurface drainage good, and acidity strong. Prior to 1913 this farm was in a low state of fertility, producing low yields of grain. Three tons of raw rock phosphate (100-mesh) containing 12.5% phosphorus were applied per acre during the period from 1913 to 1920. A rotation of corn, corn, oats, red clover, and wheat was practiced with marked increases in crop yields due to use of rock phosphate. In order to grow sweet clover and alfalfa, dolomitic limestone was applied in 1925 at the rate of 4 tons per acre.

Mann farm.—This farm is located in Iroquois County in the north central part of Illinois. It consists of level, well-drained prairie soil, mapped as brown silt loam (Muscatine). The organic matter content is high, surface and subsurface drainage good, and acidity slight. During the period 1901 to 1920, the field sampled had received 4 tons of limestone and 4 tons of raw rock phosphate (100-mesh) containing 12.5% phosphorus. The rotation practiced has been corn, corn, wheat, and alfalfa. At first only one crop of alfalfa was removed per year, but of late years two crops have been taken and the succeeding growth plowed under.

Hopkins' "Poorland Farm."—This farm is located in Marion County in the south central part of Illinois. It is mapped as gray silt loam on tight clay which is poorly drained. The surface and subsurface drainage is poor, organic matter content low, and acidity very strong. This farm had been abandoned for 5 years prior to 1904 because it would grow only poverty grass, red sorrel, and weeds. During the period from 1904 to 1920 a total of about 5 tons of limestone and 2 tons of rock phosphate were applied. In 1912 manure also was added at the rate of 6 loads per acre over the entire field.

SAMPLING THE FIELDS

On the Mies farm the limed and phosphated field was sampled by selecting a representative area, 10 rods by 10 rods, and collecting borings at 5-rod intervals. Nine borings were made at the respective depths of 0 to 8 inches and 8 to 16 inches and five borings at 16 to 24 inches. All borings were kept separate. An adjoining field which had not received lime or phosphate served as a check and was sampled in a similar manner.

The same general method was used in sampling the Mann farm. Borings were collected from a check strip, 4 rods by 10 rods, which had received an application of limestone and from a representative area of the field which had received both limestone and rock phosphate.

Samples of soil from the Hopkins' "Poorland Farm" were secured from untreated, limestone, and limestone and rock phosphate treated areas of a 40-acre field. Each of the three areas was sampled by collecting 20 borings at the respective depths of 0 to 7 inches, 7 to 14 inches, and 14 to 21 inches. From these borings composite samples representing each of the above-mentioned depths were prepared for analysis.

PREPARATION OF SOIL SAMPLES AND CHEMICAL METHODS

The samples of the soils were air dried, 20-meshed for the available phosphorus, potassium, and pH determinations, 40-meshed for the replaceable calcium and magnesium determinations, and 100-meshed for the total phosphorus determination.

The readily available or soluble phosphorus was determined by Truog's (12) method. The soil was extracted for one-half hour with 0.002 N sulfuric acid buffered with ammonium sulfate to a pH of 3.0. The ratio of soil to solvent used was 1 to 400, that is, 0.5 gram of soil was shaken with 200 cc of the acid. The total phosphorus was determined by sodium carbonate fusion and subsequent colorimetric determination according to an unpublished method of Truog and Rothermel. The pH of the soil was determined colorimetrically. The available or replaceable potash was determined according to an unpublished method by Volk and Truog. The replaceable calcium and magnesium were extracted by leaching 10 grams of the soil with 500 cc of N ammonium acetate. The total nitrogen was determined according to the usual Kjeldahl method.

It should be noted that the phosphorus dissolved by 0.002 N sulfuric acid from soils having been treated with considerable amounts of rock phosphate should not all be classed as readily available in the ordinary sense. The phosphorus of rock phosphate practically all dissolves in this solvent, yet the availability of this phosphorus is probably lower to most plants than the natural soil phosphates dissolved by this same solvent. For these reasons, in this paper, the phosphorus dissolved by 0.002 N sulfuric acid from areas treated with rock phosphate is termed soluble phosphorus rather than readily available.

DISCUSSION OF RESULTS

SOLUBLE AND AVAILABLE PHOSPHORUS AND CROP YIELDS

The use of rock phosphate has increased the amount of soluble phosphorus per acre in the surface layer to the extent of 370 pounds on the Mies farm, 217 pounds on the Mann farm, and 224 pounds on the Hopkins farm. These amounts of soluble phosphorus were present although no rock phosphate had been applied since 1920.

The available phosphorus contents of the untreated areas on the Mies and Hopkins farms were very low, indicating the need of a phosphatic fertilizer. On the Hopkins farm (3) in 1912 the increase in wheat yields due to the addition of rock phosphate was approximately 20 bushels per acre. On the Mies farm (10) the 12-year average increase per acre due to phosphorus alone was 13 bushels of corn, 17 bushels of oats, 8 bushels of wheat, and an immense increase in the crops of clover.

The amount of available phosphorus on the unphosphated area of the Mann farm was higher than is usually found in most untreated corn belt soils. This area had received an application of 4 tons of limestone per acre. Alfalfa was also grown regularly in the rotation. The adjoining neighbor's field, which was unlimed, was tested and found to contain 56 pounds of soluble phosphorus per acre, while the Mann area just described contained 156 pounds per acre. The use of limestone with the growing of alfalfa evidently accounts for the relatively high amount of available phosphorus present. That applications of limestone and the growing of legumes may, at least for some time, increase the amount of available phosphorus is also brought out in the data from the Hopkins farm in which the amount is nearly trebled. These data are in accord with the writer's experience in testing soils on a number of the Illinois experiment fields where limestone was used in conjunction with sweet clover or alfalfa.

It will be noted that the yields of corn and wheat on the Mann farm are unusually high, and the same would be true of the alfalfa yields had as many cuttings been removed as possible. On both the Mann and Mies farms rock phosphate has made possible good yields and given notable increases. On the Hopkins farm rock phosphate originally gave very marked increases in yields. In recent years, limestone alone has given good crops, partly due to the fact that it has made possible the growing of sweet clover which, in turn, over a period of years, has been instrumental in the transformation of some of the native phosphates into readily available form, as already mentioned.

Judging from the amount of available phosphorus present in the unphosphated area of the Mann farm, it would seem that there is sufficient present for good crops, and the yields actually produced would probably be considered satisfactory by some people. However, when rock phosphate was added, the yields (4) were increased to unusually high levels. This was made possible because the soil is high in organic matter and has excellent physical properties.

From the data in Table 4 it will be noted that about 25% more soluble phosphorus was recovered from the phosphated areas by three extractions than by one extraction. About 90% of the applied phosphorus is accounted for on the Mies and Mann farms by the three extractions plus that removed by crops. It was not possible to obtain a complete record of the total amount of rock phosphate applied and of crop yields on the Hopkins farm. It is believed that somewhat more than the assumed 2 tons of rock phosphate have been applied. This would account for the high calculated percentage of applied phosphorus recovered on the Hopkins farm.

DOWNWARD MOVEMENT OF PHOSPHORUS

From the data presented in Tables 1, 2, and 3 it is apparent that there has been an appreciable downward movement of the phosphorus into the subsurface and subsoil on the more open and lighter textured soils of the Mann and Mies farms. On the more compact soil of the Hopkins farm there was a definite movement of phosphorus into the 7- to 14-inch horizon, but only a slight movement into the 14- to 21-inch depth. The increases in amounts of soluble phosphorus on the phosphated areas over the unphosphated areas, due to the downward movement of phosphorus into the 8- to 16-inch horizons on the Mies and Mann farms, were 32 and 21 pounds per acre, respectively, while on the Hopkins farm the increase in the 7- to 14-inch depth was 64 pounds per acre of soluble phosphorus. In the 16- to 24-inch depths of the phosphated areas of the Mies and Mann farms, the increases in soluble phosphorus over the unphosphated areas were practically the same, 22 pounds and 21 pounds, respectively. On Hopkins farm only 6 pounds more soluble phosphorus were found in the 14- to 21-inch horizon of the phosphated area than in the unphosphated. The tight clay layer encountered at a depth of 18 inches probably checked the downward movement of the phosphorus on the Hopkins farm. These results indicate quite clearly the influence of soil texture and structure on phosphate movement. Stephenson and Chapman (11) found that appreciable amounts of phosphorus penetrated below the surface foot in light to medium-textured soils, but that there was little or no movement downward in the heavy soils.

On all three of the farms, the growing of deep-rooted legumes was extensively practiced, and the phosphorus liberated in the decay of these roots may have increased the amount of available phosphorus in the subsurface and subsoil. The water moving down the fairly large channels left by the decayed roots of the alfalfa and sweet clover also facilitated the downward movement of the phosphorus mechanically into the subsurface and subsoil. The fairly high annual precipitation, which is usually between 35 to 40 inches in this region, probably accelerated the downward movement of phosphorus.

The data in Tables 1 and 3 indicate but little variation in the amounts of available or soluble phosphorus in the borings from the untreated soils but considerable variation in the phosphated areas. Unevenness in the spreading of the rock phosphate may account for this lack of uniformity. Those surface borings which were higher in soluble phosphorus than the average had corresponding subsurface and subsoil borings which were also higher than the average. This indicates that the rate of application of rock phosphate materially affects the rate of downward movement of phosphorus.

TOTAL PHOSPHORUS

The data in Tables 1, 2, and 3 reveal no distinct correlation between the amounts of total and soluble phosphorus in the untreated areas of the soils. The addition of rock phosphate very markedly raised the total phosphorus content of all three soils.

TABLE 1.—*Soluble or available and total phosphorus, replaceable calcium and magnesium, and the pH of soils taken at various depths from the Mies farm.*

Boring No.	Untreated, check						Treated, 4 tons lime and 3 tons rock phosphate					
	0–8 in.		8–16 in.		16–24 in.		0–8 in.		8–16 in.		16–24 in.	
	pH	Available P, lbs. per acre	pH	Available P, lbs. per acre	pH	Available P, lbs. per acre	pH	Soluble P, lbs. per acre	pH	Soluble P, lbs. per acre	pH	Soluble P, lbs. per acre
1	4.8	29	5.8	22	5.8	14	5.8	768	5.8	134	5.8	48
2	5.2	26	6.0	17	—	—	6.0	384	6.0	48	—	—
3	4.8	24	5.8	14	5.7	14	6.2	420	5.8	48	5.8	36
4	4.8	22	5.8	14	—	—	6.2	396	6.0	60	—	—
5	4.8	24	5.8	14	5.6	12	6.0	384	5.8	50	5.8	36
6	4.7	22	5.8	17	—	—	6.2	372	6.0	43	—	—
7	4.8	29	6.0	24	6.7	14	6.2	365	5.8	46	5.8	38
8	4.8	22	5.7	19	—	—	5.8	480	6.0	60	—	—
9	5.0	26	5.8	22	5.6	14	5.8	360	5.8	46	5.8	34
Average	4.9	25	5.8	18	5.9	14	6.0	395*	5.9	50*	5.8	36*
Increase due to limestone and phosphate								370		32		22

Composite sample, untreated check					Composite sample, treated with 4 tons lime and 3 tons rock phosphate				
0–8 in.			16–24 in.		0–8 in.			16–24 in.	
Total P, lbs. per acre	M. E. replaceable		M. E. replaceable		Total P, lbs. per acre	M. E. replaceable		M. E. replaceable	
	Ca	Mg	Ca	Mg		Ca	Mg	Ca	Mg
1,020	7.7	3.5	8.9	4.3	1,460	9.5	2.5	10.0	5.1

*Boring No. 1 was excluded when averages were computed.

TABLE 2.—*Soluble or available and total phosphorus, replaceable calcium and magnesium, and the pH of soils taken at various depths from the Mann farm.*

Boring No.	Check, 4 tons lime						Treated, 4 tons lime and 4 tons rock phosphate					
	0–8 in		8–16 in.		16–24 in.		0–8 in.		8–16 in.		16–24 in.	
	pH	Available P, lbs. per acre	pH	Available P, lbs. per acre	pH	Available P, lbs. per acre	pH	Soluble P, lbs. per acre	pH	Soluble P, lbs. per acre	pH	Soluble P, lbs. per acre
1	5.8	110	5.8	48	6.5	22	6.0	456	5.8	86	5.7	38
2	7.0	120	6.7	48	—	—	6.0	384	6.0	77	—	—
3	6.7	204	6.4	53	6.8	24	6.0	336	6.0	58	5.8	34
4	6.5	216	6.5	53	—	—	6.3	384	6.3	77	—	—
5	6.6	221	6.5	53	7.3	24	6.4	432	6.7	82	6.8	53
6	6.6	149	6.5	50	—	—	6.1	360	6.1	62	—	—
7	6.5	139	6.5	48	7.1	24	6.0	336	5.9	58	5.8	55
8	6.3	120	6.4	46	—	—	6.0	312	5.8	58	—	—
9	6.0	125	6.1	48	6.5	19	6.1	360	5.8	77	5.7	38
Average	6.4	156	6.4	50	6.8	23	6.1	373	6.0	71	6.0	44
Increase due to phosphate								217		21		21

Composite sample, check, 4 tons lime				
0–8 in.			16–24 in.	
Total P, lbs. per acre	M. E. replaceable		M. E. replaceable	
	Ca	Mg	Ca	Mg
900	14.4	4.0	12.0	5.5

Composite sample, treated, 4 tons lime and 4 tons rock phosphate				
0–8 in.			16–24 in.	
Total P, lbs. per acre	M. E. replaceable		M. E. replaceable	
	Ca	Mg	Ca	Mg
1,560	9.3	2.5	5.7	2.0

TABLE 3.—*Soluble or available and total phosphorus, replaceable calcium and magnesium, and the pH of soils taken at various depths from the Hopkins "Poorland Farm," each sample a composite of 20 borings.*

Treatment	Depths of samples										
	0–7 in.					7–14 in.		14–21 in.			
	pH	Soluble or available P, lbs. per acre	Total P, lbs. per acre	M. E. Replaceable		pH	Soluble or available P, lbs. per acre	pH	Soluble or available P, lbs. acre	M. E. replaceable	
				Ca	Mg					Ca	Mg
None	4.5	28	800	2.5	1.2	4.4	24	4.3	10	1.8	1.3
Lime 5 tons	6.8	80	810	12.8	1.5	4.8	32	4.5	12	1.9	1.4
Lime 5 tons Rock phosphate 2 tons	7.2	304	1,100	16.1	1.3	5.5	88	4.8	16	2.0	1.5
Increase due to phosphate		224					56		4		

TABLE 4.—*Phosphorus recovered by crops and extracted with 0.002 N H_2SO_4 from three Illinois farms after many years cropping and treatment with limestone and rock phosphate.*

Treatment*	No. of years treated	Pounds per acre of phosphorus				Percentage of applied phosphorus recovered 0–24 in. depth by extraction alone and with crops†				Crop yields per acre				
		Applied	Removed by crops	Sol. in .002 N H_2SO_4 0–24 in.†		One extraction		Three extractions		Corn, bu.	Wheat, bu.	Oats, bu.	Alfalfa and clover, tons	Cowpeas, tons
				One extraction	Three extractions	Extract alone, %	Plus crops, %	Extract alone, %	Plus crops, %					
Mies Farm														
None	—	—	—	57	—	—	—	—	—	39	21.5	31	Failed	
L+RP	18	750	150	481	601	56.5	76.6	72.5	92.5	52	29.5	48	2	
Mann Farm														
None	—	—	—	120‡	—	—	—	—	—	—	—	—	—	
L	30	—	—	229	—	—	—	—	—	45	19	42	1	
L+RP	30	1,000	406	488	610	36.8	77.4	49.0	89.6	70	50	65	2–3	
Hopkins Farm														
None	—	—	—	62	—	—	—	—	—	13	11	—	—‖	0.83
L	26	—	—	124	—	—	—	—	—	31	28	—	—	1.40
L+RP	26	500§	106	408	510	69.2	90.4	89.6	110.8	35	35	—	—	1.50

*L = Lime; RP = Rock Phosphate.
†In the case of the Hopkins farm these depths were 0–21 inches.
‡Untreated sample from neighbor's adjoining field.
§Approximately.
‖Sweet clover.

The data in Table 5 show a close correlation between the total amounts of phosphorus found by chemical analysis and the amounts arrived at by calculation on the basis of the amounts originally present, applied, and removed in crops. This indicates that the figures used for the amounts of phosphorus applied and removed must have been fairly accurate, as were also the sampling and analysis of the soils.

INFLUENCE OF LIME APPLICATION ON REACTION AND PHOSPHATE AVAILABILITY

The data in Table 1 reveal that the addition of 4 tons of limestone and 3 tons of rock phosphate on the Mies farm had reduced the soil acidity from a pH of 4.9 to a pH of 6.0 in the plowed layer. The use of limestone and rock phosphate did not appear to influence the pH of the soil below the 8-inch depth. The limed and phosphated portion of the Mann farm was more acid than the limed area. The slight increase in acidity may be attributed to the removal of larger amounts of calcium by the abundant crops grown on the phosphated land.

TABLE 5.—*Comparison of the total amounts of phosphorus present in phosphated areas of three farms with amounts calculated on the basis of amounts applied, removed, and present in unphosphated areas.*

	Mies farm	Mann farm	Hopkins farm
Pounds of phosphorus per acre present at start of phosphate treatment (amount now present in untreated area plus amount removed by crops during period under consideration)	1,091	1,085	859
Net number of pounds of phosphorus per acre added (amount of phosphorus applied as rock phosphate, minus amount removed by crops)	600	594	394
Calculated total amount which should be present	1,691	1,679	1,253
Actual total amount found by chemical analysis	1,460	1,560	1,100

The data in Table 2 show that the untreated surface soil on the Hopkins farm was strongly acid, having a pH of 4.5. The use of limestone reduced the acidity in all three horizons sampled, but to the greatest extent in the surface 7 inches. There also was a slight reduction in the soil acidity where applications of rock phosphate were made. There are not sufficient data in this investigation to draw a definite conclusion as to the neutralizing value of rock phosphate.

Truog (14) indicates that an abundance of lime helps to keep the phosphate tied up with calcium in the form of the readily available calcium phosphate. He now states that a pH of 6.5 or higher is necessary in order to keep a considerable portion of the phosphorus in readily available form, and that most agricultural crops grow

best in the pH range 6.5 to 7.5. Most agricultural crops can utilize rock phosphate to greater advantage when it is applied to very slightly acid soils than when applied to alkaline ones. Truog (13) has shown that plants containing a relatively high calcium oxide content have a relatively high feeding power for the phosphorus in rock phosphate. Alfalfa and sweet clover are relatively high in calcium oxide content, and the growing of these legumes regularly in the rotation on the farms investigated no doubt accounts for the efficient use of rock phosphate. The pH of the limed and phosphated land of these farms is believed to be about ideal for the maximum growth of most agricultural crops. The growing of deep-rooted legumes on these farms, and the practice of turning under a large portion of these crops has increased the available phosphorus content of the soils. This has been of special advantage to the other crops grown that are not such efficient feeders on rock phosphate.

REPLACEABLE CALCIUM AND MAGNESIUM

In this study the amount of replaceable magnesium present is of special interest since rock phosphate has been used. Truog (15) has indicated that an adequate supply of readily available magnesium is essential in the soil in order that the crops may use rock phosphate effectively, because magnesium acts as a phosphorus carrier in plant metabolism. Loew (7) proposes the theory that a proper calcium-magnesium ratio, varying with the type of plant, is necessary for the proper growth and development of the plant. According to Loew's work, legumes require a 3:1, cereals a 1:1, and corn a 2:1 calcium-magnesium ratio for best growth.

The calcium-magnesium ratio of 3:1 on the treated portions of the Mies and Mann farms is in harmony with favorable crop yields reported. On the Hopkins farm the crop yields have been quite good for that particular soil type, although the calcium-magnesium ratio was about 12:1. Just what influence a more favorable calcium-magnesium ratio would have on the crop yields of the Hopkins farm is a question of interest.

AVAILABLE POTASH AND TOTAL NITROGEN

The amounts of available potash and total nitrogen present in the soils of the three farms are given in Table 6. Since according to Volk and Truog about 200 pounds of available potash per acre in the surface soil are sufficient for good yields of general farm crops, it is apparent that the soils of the Mann and Mies farms are very well supplied with available potash, even including the subsoils. This accounts, partly, for the very favorable yields produced when lime and phosphate are supplied. The soils of the Hopkins farm apparently lack available potash, although not so seriously where both lime and phosphate have been applied. If the amounts of available potash in the surface soils of the limed and phosphated areas of the Hopkins and Mies farms are compared with the amounts in the untreated areas, it is found in all cases that the system of using lime and rock phosphate and the growing of legumes regularly has resulted in an increased amount of available potash.

The same is true as regards total nitrogen on these two farms. Apparently the lime and phosphate have made the legumes grow vigorously so that they have been able to feed appreciably on difficultly available forms of potash like feldspar and mica and have

TABLE 6.—*Available potash and total nitrogen in the soils and subsoils of the variously treated areas of the three farms.**

Depth of sample, inches	Pounds per acre of available K_2O and total N under treatments indicated					
	Check, untreated		Lime		Lime and rock phosphate	
	Available K_2O	Total N	Available K_2O	Total N	Available K_2O	Total N
			Hopkins Farm			
0–7	124	2,580	128	2,900	164	3,040
7–14	90	1,980	99	2,140	95	2,220
14–21	86	900	84	900	124	920
			Mann Farm			
0–8			461	5,970	415	4,900
8–16			336	4,500	288	3,700
16–24			292	1,960	250	2,500
			Mies Farm			
0–8	386	4,360			485	4,970
8–16	413	3,980			420	4,660
16–24	401	3,120			396	3,500

*The writer is indebted to Dr. N. J. Volk for making the potash analyses and to Professor E. J. Graul for making the nitrogen analyses.

fixed notable amounts of nitrogen, and then, through the addition of their residues to the soil, have added to the supply of readily available potash and total nitrogen. In the case of the Mann farm, the limed area contains more available potash and total nitrogen than the limed and phosphated area. The amounts of these constituents are, however, so large in both cases that the differences are not of much significance, especially since both areas are very fertile, even the unphosphated area containing ample amounts of available phosphorus to grow good crops. The differences are probably due to inherent natural differences in the soils of the two areas.

SUMMARY

A study was made of the availability and downward movement of phosphorus in the soils of three Illinois corn belt farms to which liberal amounts of rock phosphate had been applied during the past 25 to 30 years. In all three cases, rock phosphate has given satisfactory results. Surface, subsurface, and subsoil samples were secured in 1931 from phosphated and unphosphated areas of these farms. These samples were tested for total phosphorus and that soluble in 0.002 N sulfuric acid, replaceable calcium and magnesium, soil acidity, available potash, and total nitrogen.

The amounts of soluble phosphorus on the Mies, Mann, and Hopkins farms have been increased 370, 217, and 224 pounds per acre, respectively, through the addition of rock phosphate.

The downward movement of phosphorus into the subsurface was evident on all three farms, but more so on the open textured soils where there was an appreciable movement into the 8- to 16- and 16- to 24-inch depths. On the more compact soil there was a definite movement into the 7- to 14-inch depth, but only a slight movement into the 14- to 21-inch depth. It is believed that the phosphorus has been carried downward largely mechanically by gravitational water. The decay of the roots of the deep-rooted legumes, alfalfa and sweet clover, no doubt, has also increased the amounts of soluble phosphorus in the subsurface and subsoil, although the apparent importance of this factor in the downward translocation of essential fertilizer elements is lessened when the data for available potassium and total nitrogen are studied in this connection.

The amount of phosphorus recovered by weak acid extraction, plus that removed by crops, accounts for 90% or more of the total applied.

The use of limestone has reduced the acidity to a marked extent in the plowed layer and to a slight degree in the subsurface and subsoil strata. There is some indication that on the Hopkins farm applications of rock phosphate have reduced acidity slightly. The favorable pH range of 6.0 to 7.0 of the limed and phosphated soils on these farms no doubt has had a direct bearing upon the amounts of available phosphorus present and the good crop yields obtained.

The calcium-magnesium ratio on the Mies and Mann farms is about ideal for most agricultural crops, while on the Hopkins farm it is rather unfavorable. Whether better yields could be secured by properly adjusting this ratio is a subject that needs investigating.

The use of lime and rock phosphate with the growing of legumes regularly in the rotation has apparently increased the amounts of available potash and total nitrogen in the surface soil of the Hopkins and Mies farms. In the case of the Mann farm, this relationship has apparently been masked by the large amounts naturally present and the inherent irregularities in the soil.

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OAT VARIETIES HIGHLY RESISTANT TO CROWN RUST AND THEIR PROBABLE AGRONOMIC VALUE[1]

T. R. STANTON AND H. C. MURPHY[2]

This paper deals with pathologic and agronomic observations on Bond, Alber, and other varieties of oats highly resistant to crown rust, *Puccinia coronata avenae* (Corda) Eriks. and Henn. In addition, further results on Victoria[3] and some closely allied strains are reported. Summarized information on source, nomenclature, and classification of these varieties and strains is presented in Table 1.

BOND

Bond (C. I. No. 2733) was received from Australia in 1929 by the U. S. Dept. of Agriculture, together with several other newly developed Australian hybrid varieties. The Division of Foreign Plant Introduction record[4] of Bond is as follows: 80217 to 80245. Avena spp. Poaceae. Oats. From New South Wales, Australia. Seeds presented by H. Wenholz, Director of Plant Breeding of the Department of Agriculture, Sydney. Received April 20, 1929. 80229 Avena sp. Bond.

The following additional information relative to the pedigree of Bond[5] was received from Director H. Wenholz: "Bond is of the breeding *Avena sterilis* x Golden Rain * * * * * * *. The *Avena sterilis*

[1]Results of cooperative investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station, Ames, Iowa. Received for publication December 27, 1932.

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[3]MURPHY, H. C., and STANTON, T. R. Oat varieties highly resistant to crown rust. Jour. Amer. Soc. Agron., 22: 573–574. 1930.

[4]U. S. Dept. of Agriculture. Plant material introduced by the Office of Foreign Plant Introduction, Bureau of Plant Industry, April 1 to June 30, 1929 (Nos. 80019–80810). Inventory No. 99, p. 1–46, Nov., 1930.

[5]Letter to T. R. Stanton, dated Oct. 2, 1931.

strain used in this cross was received from Dr. Trabut, of Algeria, in 1918 and was described as a sport from the wild oat *Avena sterilis*."

It is evident that the high resistance of Bond to crown rust was transmitted from the Red Algerian variety (*Avena sterilis culta* Trabut). Although Bond is more or less intermediate in some morphological characters between Golden Rain and Red Algerian, the spikelet separates from its pedicel by abscission, leaving a small but distinct basal scar, and the second floret separates from the first by basifracture, as in the Red Algerian oat. On the basis of these characters, there is no question that Bond belongs to *A. byzantina*. It matures in midseason, stands up well, and produces plump, rather short, reddish-yellow kernels. The first floret bears a weak awn.

TABLE 1.—*Varieties and strains of oats resistant to crown rust (Puccinia coronata avenae) introduced into the United States from 1927 to 1931, inclusive.*

Official name	C. I. No.*	Name or designation under which received	Varietal type	Species	Color of grain
		From Australia			
Bond	2733	Bond	Bond	*Avena byzantina*	Red
Kareela	2774	Kareela	Fulghum	*Avena byzantina*	Red
		From South America			
Victoria	2401	Victoria	Victoria	*Avena sativa*	Red
Victoria	2764	Avena Victoria	Victoria	*Avena sativa*	Red
Capa	2765	Avena Capa	Capa	*Avena sativa*	Gray
Pampa†	2767	Avena 64s	Capa	*Avena sativa*	Gray
Capa	2860	Capa	Capa	*Avena sativa*	Gray
Criolla	2862	"White of the country"	Capa	*Avena sativa*	Gray
———	2863	(Without name or number)	Capa	*Avena sativa*	Gray
Alber	2766	Avena 1095a	Red Algerian	*Avena byzantina*	Red
Red Algerian	2861	"Common of the country"	Red Algerian	*Avena byzantina*	Red
Red Algerian	2867	"Common red of the country"	Red Algerian	*Avena byzantina*	Red
Berger‡	2926	Avena 1095a 1332	Red Algerian	*Avena byzantina*	Red

*C. I. indicates accession number of the Division of Cereal Crops and Diseases.

†Pampa is morphologically similar to Capa (C. I. No. 2765) and Capa (C. I. No. 2860) but differs pathologically.

‡Berger was grown in crop season of 1931–32 under detention at Sacaton, Ariz. It is morphologically the same as Alber (C. I. No. 2766).

KAREELA

Kareela (C. I. No. 2774) is of interest because it is of the Fulghum type and shows resistance to certain physiologic forms of crown rust occurring in Iowa and Kansas. It originated in Australia as a selection from Fulghum. The Division of Foreign Plant Introduction record[6] of Kareela is as follows: 80760 Avena sp. Poaceae. Oats. From Cowra, New South Wales, Australia. Seeds presented by J. T.

[6]U. S. Dept. of Agriculture. Plant material introduced by the Office of Foreign Plant Introduction, Bureau of Plant Industry, April 1 to June 30, 1929 (Nos. 80019–80810). Inventory No. 99, p. 1–46. Nov., 1930.

Pridham, [Cowra] Experimental Farm, through T. R. Stanton, Bureau of Plant Industry. Received March 21, 1929. Kareela C. 28.

Director H. Wenholz also kindly supplied the following statement[7] on Kareela: "Kareela is a selection from Fulghum which was received from the United States Department of Agriculture in 1919. * * * * * * * * we have a large number of selections from this variety which do not appear to be uniform in type."

VICTORIA AND CAPA STRAINS

Several strains of the Victoria and Capa have been introduced from South America (Table 1.) The origin of these varieties is of interest because for many years a search has been made by plant explorers in remote sections of the world for oats highly resistant to crown rust. Breeding for the development of resistant varieties was impossible so long as no satisfactory foundation stocks were available. Previous to 1929 several more or less resistant varieties were received from Australia but none showed sufficient resistance to be of much value as breeding material. It is paradoxical that varieties showing high resistance to crown rust should have been found in South America where the production of oats is relatively unimportant.

The writers have endeavored to obtain as much information as possible on the origin and development of Victoria and Capa in South America. It was believed that the original variety, which shows high resistance to crown rust, had been introduced into South America in comparatively recent years. This, however, does not seem to be the case, as, through correspondence with Dr. Enrique Klein of the Criadero Argentino de Plantas Agrícolas, Plá, Argentina,[8] the following statement was obtained:

"There is no reason for supposing that the original variety was introduced into the Río de la Plata some years before systematic selection was begun, since this type of oat, known here as white, must be considered as 'criolla,' that is to say, cultivated for a long time.

"Victoria and Capa come from the same source or variety of white criolla oats, which was supplied in 1914 by the Comisión Oficial de Distribución de Semillas de la República Oriental del Uruguay to the Instituto Fitotécnico y Semillero Nacional 'La Estanzuela' for general seeding on a large scale.

"This oat was sown as a field crop by the Semillero Nacional, and also was space planted in the nurseries of the Instituto Fitotécnico, the seed being designated as Avena 64. After harvest the individual plants were selected and designated 64a, 64b, 64c, 64d, etc.

"The writer then occupied in 'La Estanzuela' the office of chief of phytotechnical distribution. In 1919, upon the installation in Argentina of the first special establishment for the biological selection of agricultural plants, I included in my nurseries all the more promising lines of all cereals selected up to that moment in 'La Estanzuela,' and among these families were found also the lines from which have originated the oats Victoria and Capa.

[7]Letter to T. R. Stanton, dated Oct. 2, 1931.

[8]Excerpts from translation of letter written in Spanish by Dr. Enrique Klein to T. R. Stanton, November 17, 1930.

"The Capa oat had its origin in plant 64s and was distributed in Argentina for the first time in 1923.

"The Victoria oat, which you received in 1927, is an artificial [mass] population and is composed of the three lines 64q, 64r, and 64t. It was distributed for the first time in 1924.

"All the lines mentioned were selected individually and continuously, year by year from 1916 to 1919 at 'La Estanzuela' and since 1920 to the present time at Plá.

"This is all that is known concerning the origin of Capa and Victoria oats. They were not obtained by hybridization but by continued individual selection."

Upon request of the writers, the following statement[9] on the origin of Victoria and Capa oats was received also from Dr. Alberto Boerger, Instituto Fitotécnico y Semillero Nacional "La Estanzuela," at La Estanzuela, Departamento Colonia, Uruguay:

"The Victoria and Capa oats come originally from the Instituto 'La Estanzuela' which is under my direction. They were separated as pure lines from a native variety that was grown here in the field in 1915. We obtained the original lot of seed from Montevideo, although without detailed information, and for all practical purposes its general origin is Uruguay. The original seed, accessioned in our breeding books as No. 64, represents a mixture of several forms, from which we selected some particularly typical lines, of which 64s (identical with Capa) was noteworthy from the beginning because of rapid growth and comparatively good kernel quality.

"Dr. Enrique Klein, a former coworker at 'La Estanzuela,' moved to Argentina in 1920, taking with him small samples of seed of all the more important breeding lines and since that time has done further breeding work on the varieties in which you are interested. The Victoria oat also represents a pure line originating from the above mentioned mixture of forms, and in neither case is there a question of hybridization.

"The ability to resist *Puccinia coronifera* was characteristic of the entire original material, as indeed is true in general of most of the La Plata oats, which are relatively superior in this respect to those in European and North American origin. I assume that the point of question is the immunity that is the result of many decades of natural selection. This rust resistance is of fundamental significance for La Plata; without it, it would be impossible to grow oats here on a large scale. It has been repeatedly shown that oats of foreign origin develop well at first and later succumb to rust.

"To sum up, it therefore may be said also that Uruguay positively is the place of origin of the resistant Victoria and Capa oats in which you are interested. Breeding work was done here at 'La Estanzuela' until 1920, but from that time on these varieties were further developed in Argentina by Enrique Klein in his 'Criadero Argentino de Plantas Agrícolas, Plá, Buenos Aires.' "[10]

[9]Excerpts from translation of letter written in German by Dr. Alberto Boerger to T. R. Stanton, November 6, 1930.

[10]For a brief résumé of Dr. Boerger's work with oats resistant to crown rust see "Observaciones sobre Agricultura," pages 505–522. Montevideo, 1928.

It will be seen from the statements of Messrs. Klein and Boerger that the Victoria and Capa strains have been developed from a variety cultivated for many years in Uruguay and adjacent Argentina. Evidently, oat production in the Río de la Plata depends primarily on the use of varieties resistant to crown rust.

Further information on the origin, introduction, and characteristics of the various strains of the Victoria and Capa oats is given below:

VICTORIA (C. I. No. 2401).—Murphy and Stanton[11] have reported on the introduction and crown-rust resistance of Victoria. The lot of seed accessioned under C. I. No. 2401 represents an artificial population of the lines 64q, 64r, and 64t. On the basis of the pathologic data presented in this paper the population has been highly resistant to or nearly immune from crown rust and already is the parent of many hybrids.

VICTORIA (C. I. No. 2764).—The introduction of this strain of Victoria also has been reported by Murphy and Stanton.[12] It was received under the name Avena Victoria and has been distributed to some experiment stations under the name "Scasso," having been received from José M. Scasso, Agrónomo Regional, Morón, Province of Buenos Aires, Argentina. This strain has since been identified as morphologically and pathologically identical with Victoria (C. I. No. 2401).

CAPA (Avena Capa, C. I. No. 2765).—This lot of Capa seed was forwarded directly to the plant pathology section, Iowa Agricultural Experiment Station, in April, 1929, by José M. Scasso, Agrónomo Regional, Morón, Province of Buenos Aires, Argentina. The strain was received under the designation Avena Capa.

PAMPA (Avena 64s, C. I. No. 2767).—Pampa is similar to Capa (C. I. No. 2765) and was received under the designation Avena 64s. It was obtained from Dr. Alberto Boerger, Director del Instituto Fitotécnico, Departamento Colonia, República Oriental del Uruguay. The original packet of seed was forwarded directly to the plant pathology section, Iowa Agricultural Experiment Station, in August, 1929. Avena 64s has been renamed Pampa because it differs pathologically from the other Capa strains here described.

CAPA (C. I. No. 2860).—The original lot of seed of Capa (C. I. No. 2860) was received on March 20, 1930, by the Division of Cereal Crops and Diseases, from Mr. José M. Scasso, Agrónomo Regional, Morón, Province of Buenos Aires, Argentina. Mr. Scasso apparently obtained it originally from Enrique Klein's Criadero Argentino de Plantas Agrícolas, Plá, Province of Buenos Aires, Argentina.

CRIOLLA (C. I. No. 2862).—Criolla was received in the same shipment and from the same source as Capa (C. I. No. 2860.) It was forwarded under the designation "white of the country," and apparently was secured by Mr. Scasso from the Depósito de cereales, "La Rural," Buenos Aires, Ciudad. Criolla is typical of the Capa variety.

[11]See footnote 3.
[12]See footnote 3.

C. I. No. 2863.—C. I. No. 2863 is an unnamed oat received from the same source at the same time as Capa (C. I. No. 2860.) According to Mr. Scasso, this variety is "without name and without determination of origin." However, it undoubtedly is similar to if not identical with Criolla. These oats represent the original mass variety from which Capa and Victoria were selected.

These five Capa-type strains are morphologically similar but pathologically different. Capa differs primarily from Victoria because it ripens earlier and has shorter lemmas. The lemmas of Capa are gray. According to Enrique Klein, Pampa (Avena 64s) matures from 5 to 8 days earlier than Victoria. In this country the differential has been about the same during the few years in which the variety has been observed. Owing to variability in resistance to crown rust the strains of Capa probably are less promising than those of Victoria, Alber, or Bond.

RED ALGERIAN STRAINS

ALBER (Avena 1095a, C. I. No. 2766).—The Alber strain of Red Algerian was received in the same shipment and from the same source as Capa (C. I. No. 2767). This strain apparently was selected and developed at "La Estanzuela," Departamento Colonia, Uruguay, by Dr. Boerger. Alber is morphologically typical of the Red Algerian variety.

RED ALGERIAN (C. I. No. 2861).—Red Algerian (C. I. No. 2861) was received by the U. S. Dept. of Agriculture under the designation "common of the country," from José M. Scasso, March 20, 1930. This strain or lot of seed was obtained by Mr. Scasso from the Depósito de cereales de Passadore Hermanos, Morón, Province of Buenos Aires, Argentina. It is typical of the Red Algerian variety in plant and kernel characters.

RED ALGERIAN (C. I. No. 2867).—This strain of Red Algerian was received from the same source and at the same time as Red Algerian (C. I. No. 2861). According to Mr. Scasso, it was originally obtained from the Colonia Seré, F. C. O., Province of Buenos Aires, Argentina. It is typical of the Red Algerian variety. The designation "common red of the country" identifies it as the red oat commonly grown in Argentina and Uruguay.

BERGER (Avena 1095a 1332, C. I. No. 2926).—Berger was received by the Division of Cereal Crops and Diseases from Dr. Alberto Boerger, La Estanzuela, Departamento Colonia, Uruguay. Berger is closely related to the variety Alber (C. I. No. 2766) and is typical in all the plant characters of Red Algerian.

Three of the four Red Algerian strains here described have shown high resistance to crown rust when grown from fall seeding in the South. However, these strains may not prove of agronomic value for the production of fall-sown oats in the southern states owing to the inferior yielding power under these conditions that has characterized all Red Algerian strains previously tested. They have not been able to compete with the best Red Rustproof strains.

CROWN RUST REACTION

Bond (C. I. No. 2733) is outstanding from the standpoint of resistance to crown rust combined with desirable agronomic qualities. It was nearly immune from 16 forms of crown rust collected in 1931, including the most aggressive and virulent forms known to occur in the United States, Canada, and Mexico. In field tests in the central and southern oat areas of the United States in 1931 and 1932, Bond was extremely resistant to crown rust. Neither Bond, nor the two Victoria strains discussed later, have shown a susceptible reaction in greenhouse or field tests, Bond consistently showing a high type of resistance or near immunity. It is susceptible to stem rust but apparently resistant to certain forms of the loose and covered smuts of oats.

In natural epiphytotics of crown rust Kareela (C. I. No. 2774) was highly resistant at Ames, Iowa, and Manhattan, Kans., in 1931, and at Ames, Iowa, in 1932, but completely susceptible at Tifton, Ga., in 1932. It also proved susceptible when artificially inoculated with forms 1 and 29 at Ames in 1932. However, because of its desirable Fulghum type and partial resistance to crown rust Kareela warrants further study.

The two Victoria strains (C. I. Nos. 2401 and 2764) have shown high resistance to 32 physiologic forms of crown rust collected in the United States, Canada, and Mexico in the 5-year period, 1927 to 1931. These two are the only varieties known to be resistant to all of the forms collected in this period. The reaction of the Victoria strains to crown rust under field conditions in 1929–1932 and 1930–1932, respectively, has been either high resistance or near immunity. During these tests Victoria (C. I. No. 2401) was observed throughout the oat-growing regions of the United States, while Victoria (C. I. No. 2764) was grown only in the central and southern sections. Unfortunately, both strains are completely susceptible to the physiologic forms of stem rust prevalent in North America. In greenhouse and field tests, however, these oats have shown high resistance to the physiologic forms of loose and covered smuts that are prevalent in the central and southern oat areas of the United States.

Other new varieties that showed considerable resistance in natural epiphytotics of crown rust in the central and southern oat areas of the United States in 1930–1932, inclusive, were Capa (C. I. No. 2765), Pampa (C. I. No. 2767), and Alber (C. I. No. 2766). Each of these varieties has been tested with 27 physiologic forms, including those most virulent and widely distributed. Capa (C. I. No. 2765) is resistant to 17 forms, while Pampa (C. I. No. 2767) is resistant to 13 forms. Both of these Capas are susceptible to forms 1 and 7, which are widely distributed and prevalent in the southern or winter-oat area of the United States but resistant to most of the forms prevalent in the northern spring-sown oat areas. Alber is resistant to 20 forms, including those most prevalent in northern areas, and the very important southern form 7. It is not resistant to form 1. Nevertheless, this variety offers considerable promise as a fall-sown oat and should be particularly valuable for the development by hybridization of crown-rust-resistant varieties adapted to the South.

Capa (C. I. No. 2860), Criolla (C. I. No. 2862), the unnamed oat (C. I. No. 2863), Red Algerian (C. I. No. 2861), Red Algerian (C. I. No. 2867), and Berger (C. I. No. 2926) are other varieties worthy of mention from the standpoint of resistance to crown rust. These varieties have not been subjected to specific physiologic forms, but they have shown moderate resistance to crown rust under field conditions at Ames, Iowa, in 1932. Capa (C. I. No. 2860) and the Red Algerian strains C. I. Nos. 2861 and 2867 also showed considerable resistance in a natural epiphytotic of crown rust at Tifton, Ga., in 1932. This group of varieties is of particular interest because it apparently is the source from which some of our most highly resistant strains were obtained by selection and also by hybridization.

AGRONOMIC DATA

The agronomic value of these new varieties for the most part is yet to be determined. A few data on their relative yielding power are available from nursery experiments. The location of the experiments, the years in which varieties were grown, and acre yields obtained, are shown in Table 2.[13]

The data in Table 2 indicate that Bond, the variety nearly immune from crown rust, may be of considerable agronomic promise. The yields obtained at all five stations in 1932 are rather favorable. Kareela, likewise, has made a good record from spring seeding. The low yield at Tifton, Ga., resulted from a severe natural epiphytotic of forms 1 and 7 of crown rust. The Victoria and Capa strains appear to be of little agronomic promise in the United States, although the two strains, Capa (C. I. No. 2765) and Pampa (C. I. No. 2767), have made fair yields in the 3 years they were grown at Ames, Iowa. The Red Algerian strains, while showing high resistance to crown rust, may not be able to compete in yield with the best Red Rustproof strains. Mr. R. P. Bledsoe,[14] Agronomist, Georgia Experiment Station, Experiment, Ga., comments on the behavior of the Victoria, Capa, and Alber strains grown at that station as follows: "In regard to Victoria and other varieties on which I sent you yield data, it does not look to me that any of these varieties have any commercial value in this section. Their yields are so low as compared with other strains, that it would not pay to grow them. Their value must be in connection with breeding for rust resistance or crossing with better adapted varieties."

As stated by Mr. Bledsoe, it is probable that the greatest value of

[13]Data were obtained at the following places: Tifton, Ga., in cooperation with the Georgia Coastal Plain Experiment Station and the Georgia State College of Agriculture at Athens, H. S. Garrison, Assistant Agronomist; Experiment, Ga., courtesy of the Georgia Agricultural Experiment Station, R. P. Bledsoe, Agronomist; Ames, Iowa, in cooperation with the Iowa Agricultural Experiment Station, L. C. Burnett, Agent and Chief in Plant Breeding; Manhattan, Kans., in cooperation with the Kansas State Agricultural College, J. H. Parker, Agronomist, and W. H. von Trebra, Agent; North Platte, Nebr., in cooperation with the Nebraska Agricultural Experiment Station, N. E. Jodon, Junior Agronomist; Akron, Colo., in cooperation with the Colorado Agricultural Experiment Station, J. J. Curtis, Junior Agronomist.

[14]Letter to T. R. Stanton, dated Sept. 8, 1932.

Table 2.—*Yields of 11 oat varieties resistant to crown rust and of 7 standard varieties grown in replicated nursery rows at seven agricultural experiment stations for one or more years.*

Variety	C. I. No.	Location of station, number years varieties were tested, and yield of grain in bushels per acre							
		Rosslyn, Va., 1 year (fall sown)	Tifton, Ga., 1 year (fall sown)	Experiment, Ga., 2 years (fall sown)	Ames, Iowa		Manhattan, Kans., 1 year	North Platte, Nebr., 1 year	Akron, Colo., 1 year
					Crown-rust nursery 3 years	Agronomic nursery 1 year			
				Crown-rust-resistant Varieties					
Bond	2733	—	29.6	—	59.0*	64.0	62.5	20.8	19.5
Kareela	2774	—	5.8	—	—	69.0	57.6	22.0	31.9
Victoria	2401	22.4	21.5	62.2	45.2	52.8‡	72.3	—	—
Victoria	2764	—	29.6	56.6	43.1	—	—	—	—
Capa	2765	—	19.6	51.3	59.0	—	—	—	—
Pampa	2767	—	—	48.6	57.2	—	—	—	—
Capa	2860	—	13.8	—	—	—	—	—	—
Criolla	2862	—	13.6	—	—	—	—	—	—
Alber	2766	—	40.2	79.5	30.3†	—	—	—	—
Red Algerian	2861	—	35.0	—	—	—	—	—	—
Red Algerian	2867	—	33.0	—	—	—	—	—	—
				Standard Agronomic Varieties					
Winter Turf	—	34.2‖	—	—	—	—	—	—	—
Red Rustproof	518-3	—	40.6§	—	—	—	—	—	—
Red Rustproof (Ga. No. 174)	2809	—	—	103.8	—	—	—	—	—
Iogold	2329	—	—	—	67.5	56.0**	—	—	—
Iowar	847	—	—	—	—	—	—	24.8	—
Fulghum	708	—	—	—	—	—	59.4	—	—
Brunker	2054	—	—	—	—	—	81.0	—	22.0

*Yield for 1932 only.

†Average yield of 50.0 and 10.5 bushels for 1930 and 1931, respectively. No yield whatever was obtained in 1932 owing to the manifestation of an extreme winter habit and consequent failure of maturity.

‡Yield obtained in 1931. Nearest Iogold check yield was 60.5 bushels per acre.

‖Average yield of eight Winter Turf strains, a standard type.

§Yield of the one highest-yielding Red Rustproof strain, Texas 1415-14.

**Yield of nearest Iogold check to Bond and Kareela in 1932.

these new crown-rust-resistant oats will be for breeding higher yielding and more desirable agronomic types. For certain sections, however, Bond and Alber may prove of agronomic value without further breeding.

SUMMARY

Information on the origin, introduction, nomenclature, and probable agronomic value of certain new varieties of oats resistant to or nearly immune from crown rust is reported.

Bond (C. I. No. 2733), a new hybrid variety from Australia, is outstanding from the standpoint of resistance to crown rust in combination with desirable agronomic characters.

Kareela (C. I. No. 2774) was originated in Australia as a selection from Fulghum and has shown partial resistance to crown rust. Under natural epiphytotics it was highly resistant at Ames, Iowa, and Manhattan, Kans., in 1931, and at Ames, Iowa, in 1932, but completely susceptible at Tifton, Ga., in 1932.

The two Victoria strains (C. I. Nos. 2401 and 2764) have shown high resistance to 32 physiologic forms of crown rust collected in the United States, Canada, and Mexico in the 5 years from 1927 to 1931.

Other new varieties that show considerable resistance under natural epiphytotics of crown rust are Capa (C. I. No. 2765), Pampa (C. I. No. 2767), and Alber (C. I. No. 2766). Still other new varieties worthy of consideration with respect to resistance to crown rust are Capa (C. I. No 2860), Criolla (C. I. No. 2862), the unnamed oat (C. I. No. 2863), Red Algerian (C. I. Nos. 2861 and 2867), and Berger (C. I. No. 2926).

Bond produced favorable yields at five stations in 1932, indicating that it may be of agronomic promise. Kareela has produced favorable yields from spring seeding only. Alber has equaled the yields of the best Red Rustproof strains when grown from fall seeding in south Georgia in the crop year 1931-32.

The various strains of Victoria and Capa have been generally low in yield and probably are of little or no agronomic value in themselves. The chief value of these new crown-rust-resistant strains, including Bond and Kareela, will be for the development of more desirable agronomic varieties by hybridization.

SELECTION WITHIN BURT OATS[1]

Arthur Anderson and T. A. Kiesselbach[2]

Burt oats are widely adapted and extensively grown, especially in the more southern part of the United States. This variety has long been recognized as rather variable in many of its characteristics.[3] Due largely to its reddish color, it has not proved as popular as white or yellow sorts where these are adapted. Burt oats have been grown at the Nebraska Agricultural Experiment Station since 1905 and as an average of 25 years have exceeded the more popular Kherson variety by 4 bushels per acre.

Due to its high yield and likelihood of containing disease-resistant strains, selection was undertaken within the Burt variety at the Nebraska Station in 1920. Because of the commercial advantages of light grain color, primary interest was attached to the feasibility of isolating productive light-colored strains. Seeds classified according to color were space planted to form the initial nursery. The seed from 735 of the most promising and productive plants was close drilled in 8-foot rows in 1921. Elimination on the basis of inferior yield and unattractive vegetative development proceeded during 1921 and 1922 with the result that only 150 strains were advanced to the replicated five-row block nursery in 1923. Sixty-four of these strains were grown during the 5-year period, 1923–27, in five-row blocks, replicated from 4 to 10 times. The number was further reduced to 35 in 1928.

CLASSIFICATION OF SELECTIONS AS TO GRAIN COLOR

A record of the color of the grain produced by the various selections was maintained throughout the period grown, as well as the color of the initial seeds planted. The color classification of the progenies was based largely on the mass appearance of the grain. Color expression among these strains was found to be affected materially by environmental conditions.

The seeds producing the 735 mother plants may be grouped as follows: 43% white, 28% light yellow, and 29% red to black. When classified according to the grain color of the mother plants and their immediate progeny, 4% of the 735 selections were found to be white, 30% yellow, and 66% colored. The term "colored" will be understood herein to apply to any color other than white or yellow. In a large number of instances the strains originally classed as white or yellow were subsequently observed to show color. There was a much greater tendency for the dark seeds to reproduce their color than for the light seeds.

With respect to the 64 strains tested during 7 years, only 4 were classed as white to yellow throughout the period and 15 ranged from

[1]Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., as paper No. 128, Journal Series. Published with the approval of the Director. Received for publication January 10, 1933.

[2]Agronomists.

[3]Coffman, F. A., Parker, J. H., and Quisenberry, K. S. A study of variability in the Burt oat. Jour. Agr. Res., 30: 1–64. 1925.

dark red or brown to black, while the remaining 45 were classed as intermediate. There was a wide range of color within the intermediate group and every strain therein was classed as white or yellow during one or more years. These strains have been arranged in Table 1 in the order of increasing color intensity.

TABLE 1.—*Description and yields of 64 selections of Burt oats classified according to grain color.*

Strain No.	Date headed	Date ripe	Plant height, in.	Smut, 3-yr. av.,%†	Average yield per acre in bushels*			
					5 years, 1923–27		7 years, 1923–30	
					Actual	Relative	Actual	Relative
				Original Unselected Burt				
—	June 11	July 6	31	—	41.0	100	47.9	100
				White to Yellow Selections				
6	June 11	July 6	30	9	44.1	108	51.2	107
44	June 10	July 3	29	2	42.1	103	48.8	102
3	June 12	July 6	30	16	42.4	103	48.8	102
1	June 12	July 6	31	9	40.9	100	—	—
Av.	June 11	July 6	30	9	42.4	103	49.6	104
				Intermediate Selections (Gray and Light Red to Light Brown)				
11	June 12	July 6	30	15	41.9	102	50.4	105
19	June 10	July 5	31	13	43.8	107	50.7	106
18	June 12	July 6	30	16	40.8	100	46.9	98
7	June 10	July 6	30	18	41.6	101	—	—
5	June 11	July 5	32	9	40.5	99	—	—
8	June 11	July 6	30	18	39.7	97	—	—
9	June 11	July 6	31	18	37.5	91	—	—
16	June 11	July 5	30	21	40.5	99	48.0	100
17	June 11	July 5	30	20	43.6	106	49.4	103
39	June 11	July 5	31	10	40.5	99	48.3	101
35	June 13	July 6	30	21	45.9	112	52.4	109
24	June 12	July 6	31	17	42.3	103	49.0	102
40	June 12	July 4	31	17	40.3	98	—	—
23	June 12	July 6	30	22	46.2	113	52.8	110
27	June 10	July 5	32	9	42.2	103	47.8	100
4	June 11	July 5	29	5	43.3	106	49.5	103
33	June 12	July 6	29	14	47.2	115	56.7	118
41	June 11	July 4	29	9	38.9	95	—	—
28	June 12	July 6	30	9	46.7	114	49.3	103
29	June 11	July 5	30	7	42.7	104	49.3	103
12	June 10	July 4	30	11	39.2	96	46.3	97
13	June 11	July 5	30	17	45.6	111	52.4	109
43	June 9	July 4	30	4	41.1	100	47.8	100
2	June 10	July 5	30	5	42.1	103	48.6	101
14	June 11	July 6	30	16	43.5	106	49.4	103
21	June 12	July 6	31	11	40.1	98	—	—
38	June 11	July 4	31	11	39.1	95	—	—
15	June 12	July 6	28	11	39.4	96	—	—

*Grown in five-row nursery blocks, replicated from 4 to 10 times annually, with the border rows discarded in determining the yield. The 1929 crop was not harvested due to damage resulting from a hail storm.

†Seed inoculated annually with local smut for these determinations.

TABLE 1.—*Concluded.*

Strain No.	Date headed	Date ripe	Plant height, in.	Smut, 3-yr. av., %†	Average yield per acre in bushels*			
					5 years, 1923–27		7 years, 1923–30	
					Actual	Relative	Actual	Relative
					Intermediate Selections (Gray and Light Red to Light Brown)			
20	June 12	July 6	31	6	40.4	99	—	—
34	June 11	July 6	31	20	42.1	103	49.2	103
47	June 11	July 6	31	8	39.8	97	—	—
45	June 11	July 6	30	22	43.5	106	51.0	106
30	June 10	July 5	31	4	42.1	103	49.3	103
32	June 11	July 5	30	9	43.8	107	50.7	106
42	June 12	July 5	32	14	43.3	106	50.3	105
25	June 10	July 6	30	7	38.3	93	—	—
22	June 10	July 6	30	15	40.4	99	—	—
31	June 9	July 4	30	5	40.6	99	—	—
36	June 11	July 4	31	12	40.6	99	47.6	99
37	June 13	July 4	30	7	39.1	95	—	—
46	June 12	July 6	31	15	38.5	94	—	—
51	June 9	July 5	30	3	43.6	106	—	—
26	June 11	July 4	30	9	39.2	96	45.5	95
64	June 9	July 6	30	10	39.0	95	—	—
10	June 11	July 6	31	28	41.0	100	47.3	99
Av.	June 11	July 5	30	16	41.6	101	49.5	103
					Dark Red and Brown to Black Selections			
48	June 10	July 6	28	2	46.1	112	—	—
54	June 10	July 5	29	24	43.0	105	—	—
49	June 10	July 6	31	10	43.2	105	—	—
50	June 10	July 6	28	2	42.8	104	—	—
52	June 10	July 4	28	3	47.4	116	52.7	110
53	June 10	July 4	28	6	46.6	114	53.2	111
55	June 11	July 6	29	27	44.1	108	50.1	105
56	June 11	July 6	30	14	41.9	102	—	—
57	June 12	July 6	29	21	41.5	101	—	—
58	June 12	July 6	29	25	42.2	103	—	—
59	June 12	July 6	29	35	42.2	103	48.5	101
60	June 11	July 7	30	32	41.6	101	48.1	100
61	June 11	July 6	29	21	42.8	104	—	—
62	June 12	July 7	29	20	40.6	99	—	—
63	June 12	July 6	28	21	39.6	97	—	—
Av.	June 11	July 6	29	18	43.0	105	50.5	105

*Grown in five-row nursery blocks, replicated from 4 to 10 times annually, with the border rows discarded in determining the yield. The 1929 crop was not harvested due to damage resulting from a hail storm.

†Seed inoculated annually with local smut for these determinations.

COMPARATIVE YIELDS

Throughout the period of testing, the original unselected Burt was grown on every sixth plat for comparison with the selections. Its average yield during the 5-year period (1923–27) was 41.0 bushels per acre and for the 7-year period (1923–30), 47.9 bushels. The check plats have also been used to calculate the annual and average yield

variability. The standard error of a single check plat determination was 2.53 and 2.56 bushels, respectively, for the 5- and 7-year periods and that for the mean of the checks 0.268 and 0.244 bushel, respectively. As based on the error of the check plats and the annual number of replications, the standard error of any strain becomes 1.12 bushels for the 5-year period and 0.97 bushel for the 7-year period. These standard errors may be used to calculate the error of any particular group of strains for the periods under consideration.

As a 5-year average, 1923–27, the 4 light-colored strains yielded 103% of the original unselected Burt, the 45 intermediate-colored strains 101%, and the 15 dark-colored strains 105%. Compared with 47.9 bushels for the original Burt over the 7-year period, the respective yields of the highest yielding individual light-, intermediate-, and dark-colored strains were 51.2, 56.7, and 53.2 bushels per acre. The three highest yielding strains of the light-, intermediate-, and dark-colored groups averaged 49.6, 54.0, and 52.0 bushels per acre, respectively. Based on the variability of check plats, differences of 2.74 and 1.58 bushels per acre are required for statistical significance for single- and three-strain comparisons. When single strains are compared with the original Burt, however, differences of 2.80 and 2.48 for the respective 5- and 7-year periods are statistically significant.

These results show that the Burt variety contains both light- and dark-colored strains that are inherently higher yielding than the variety itself. Although there is no indication that high yield and grain color are associated, high-yielding colored strains occur most frequently.

A number of the strains that have averaged high in yield have also been observed to show more or less disease resistance. For instance, strains 35, 33, and 13 showed marked resistance to stem rust in 1932.

TABLE 2.—*Comparative yield of the Burt selections grown in field plats, 1929 to 1932.*

Strain No.	Nebr. No.	Stem rust, 1932*, %	Yield per acre in bushels							
			Nursery plats†		Field plats‡					
			Av.	Rel.	1929	1930	1931	1932	Av.	Rel.
Original	Burt	40	47.9	100	64.1	76.1	63.9	54.3	64.6	100
6	526	25	51.2	107	—	—	64.8	59.7	—	—
11	517	40	50.4	105	71.5	80.4	62.5	54.1	67.1	104
19	519	40	50.7	106	68.9	72.7	64.4	60.3	66.6	103
35	529	10	52.4	109	—	—	64.1	69.2	—	—
23	527	40	52.8	110	—	—	64.2	59.6	—	—
33	520	10	56.7	118	69.9	75.7	67.5	68.3	70.4	109
28	528	25	49.3	103	—	—	66.8	58.7	—	—
13	518	5	52.4	109	65.9	69.0	64.0	69.2	67.0	104
45	521	25	51.0	106	64.5	78.1	65.4	58.3	66.6	103

*Degree of rust infection was determined according to the scale used in U.S.D.A. Tech. Bul. 143.

†Seven-year average from Table 1.

‡Three to six replications per year excepting one plat each for strains 6, 35, 23, and 28 in 1931.

Strains 44, 48, and 50 have shown resistance to smut over a period of years.

Selection during the nursery testing period was based largely on yield and general appearance. In 1929, five of the more promising, relatively light-colored strains were transferred to field plats for further testing. Four additional strains were included in the field plat tests in 1931 and 1932. Two of the highest yielding selections were not advanced to field plats because of their extremely dark color. The field plat results are reported in Table 2.

Of the strains grown in field plats, Nos. 33, 35, and 13 appear to be most promising for commercial production. These three selections fall in the intermediate-colored group but would probably grade as white oats under average Nebraska conditions. Their color has ranged from white, light yellow, and gray to very light red and light brown. Strain 33 has been the most productive of the 35 selections tested in the nursery during a 7-year period, yielding 18% more than the original Burt. It also ranked first in field plats over a 4-year period, yielding 9% more than the original.

WORLD'S DIVERSITY OF PHENOTYPES OF MAIZE[1]

N. N. KULESHOV[2]

The study of the world's principal cultivated plants carried out by the Institute of Plant Industry of U. S. S. R. with large collections gathered in different countries shows maize to be a plant having an extraordinary diversity of morphological and biological peculiarities.

Such diversity only can explain the extraordinary large area occupied in the world by *Zea mays* L. Beginning with 57° to 58° north latitude, where we may note cases of maize-growing in Canada and in the northern regions of U. S. S. R., the culture of maize, gradually increasing in importance, goes farther to the south, passing without interruption through the subtropical and tropical regions, and reaches nearly the frontier of agriculture in the southern hemisphere (35° to 40° south latitude). Among the representatives of the cultivated plants we do not know of another which occupies such a large area.

It is very interesting to notice the different conditions under which maize can grow. From the Caspian plains, situated below sea-level, maize rises up to 3,000 meters in the Andes (in Peru); from the arid and semi-arid plains of U. S. S. R., having only 250 mm of yearly precipitation, maize passes into the subtropical regions of Florida having 2,000 mm of precipitation and into the tropics of Hindustani, having 5,000 to 6,000 mm of precipitation. The short summer of Canada is known to maize just as well as the everlasting summer of tropical Colombia. About 195 million acres in the whole world are occupied by maize.

[1]Contribution from the Institute of Plant Industry, U. S. S. R. Received for publication January 15, 1933.

[2]Head of Maize Division, in collaboration with J. V. Kozhukhov, M. J. Khadjinov, B. I. Savrogne, and N. S. Arutunova.

LENGTH OF THE GROWING SEASON

One of the principal conditions insuring to *Zea mays* the possibility to cover such an area is the wonderful variability of the growing season of its varieties and strains which ranges from 60 to 70 days in the extra-early forms (Gaspé flint in Canada and Viatka corn in U. S. S. R.) to 10 to 11 months in the extra-late ones (Colombia). During the years 1926–31, we have grown about 8,000 kinds of corn brought from different countries. The results of these experiments allow us to show the geographical distribution of maize varieties with respect to their growing season.

To characterize the length of the growing season of the tested samples, we do not use the common determination of the number of days from planting to maturity because this index for any variety differs in different localities and in meteorologically different years. Instead, we use another index which has proved to be much more constant and sure, namely, *the number of leaves on the main stem of the maize-plant*. In one of the former contributions of our laboratory it was shown that the earlier the variety, the fewer the leaves on the main stem, whereas the latest maturing varieties have the maximum number of leaves.

To illustrate, the following data are given for a few of the better-known varieties: Gehu, 12 to 13 leaves; Minnesota 13, 15 to 16 leaves; Krug, 19 to 20 leaves; Boone County White, 20 to 22 leaves; and Hastings Prolific, 23 to 25 leaves.

Studies of the leaf number which is correlated with the growing season for the different maize varieties which we had at our disposal allow us to make the following conclusions:

1. The maximum variation for different individual plants (samples of different origins) was from 8 to 48 leaves. The variation for the average number of leaves in the samples was somewhat less, from 8.7 to 43.6 leaves. The whole diversity in length of the growing period of the species *Zea mays* is contained in these limits.

2. Variation in the length of the growing season differs in different countries. Thus, the Canadian varieties range only from 9 to 18 leaves, the American varieties from 10 to 27 leaves, the Transcaucasian ones from 11 to 27 leaves, and the Peruvian varieties from 14 to 33 leaves. One finds the greatest variation in growing season in the tropical mountainous countries, where they have the extra-late varieties in the lower zones and varieties approaching the very earliest forms in the mountains at the corn-growing limits.

3. The principal part of the world production is from varieties having 15 to 25 leaves. We must include in this group the varieties of the corn belt of the United States (mostly with 18 to 21 leaves), then the varieties of Argentina, Hungary, the Balkan countries, North Caucasus, etc. Corn varieties with this length of growing season account for about 86% of the world production of corn. Varieties having less than 15 leaves from the northern regions of the United States, a part of Canada, and the largest part of the U. S. S. R., etc., account for only about 7% of the world production. The late varieties having from 26 to 35 leaves contribute about 6%, and the extra-late ones, having more than 35 leaves, play a very minor

rôle with less than 1% of the world production. Of the total range in growing season provided by the species of *Zea mays*, the most intensive culture uses only a small fragment, lying mostly in the early maturing part. Till now the late-maturing varieties have not been widely spread. In accordance with this, the genetical experiments with maize have utilized almost exclusively middle-early varieties (with 14 to 24 leaves). The extra-early as well as the extra-late forms have not been used. It seems to us that even the simplest self-pollination should disclose in the latest-maturing forms new characters which till now we have not had in our experimental material.

4. Great interest is provided by detailed information on the extra-early varieties of corn. All of these belong to the flint group. According to our data, the record early ripening is given by the Gaspé flint, originating in Canada and having about 9 leaves. In 1931 this variety matured in Kharkow (50° north latitude) in 70 days. Another sample, very close in its earliness to Gaspé, was brought by N. I. Vavilov from the Chinese Turkestan. It has about 9 to 10 leaves and matured in 72 days in 1931. Further along we can name the following extra-early samples, having not more than 11 leaves: Ural Irbitt, 10.8 leaves; Beloyaroe psheno, West Siberia, 10.4 leaves; Central Region of the U. S. S. R., 10.8 leaves; Asia Minor, 10.9 leaves; and Chile, 10.7 leaves. As we see from this distribution, these varieties grow on the corn frontiers in the north, as well as in the south, and in the highest parts of mountainous regions, in general, in the most extreme parts of both hemispheres.

5. The extra-late varieties (with 42 to 44 leaves) were found in the Yucatan and in southern Colombia. They belong to the flint and the flour corn groups. The extra-late varieties are not so widely spread in the world as the extra-early ones and are generally concentrated in small regions.

In summary, we present a diagram (Fig. 1) showing the great variation in the length of growing season required by different corn varieties in different countries. In this diagram *most* of the principal corn-producing countries are represented, but unfortunately several countries are absent (Brazil, etc.), owing to the complete absence of data. The distribution shown by this diagram can not be considered as complete. Often we had not the necessary number of samples, nevertheless as a first approach to the knowledge of world variation in corn the diagram gives some interesting information.

BIOLOGY OF FLOWERING OF DIFFERENT CORN VARIETIES

The corn varieties cultivated in the United States, U. S. S. R., and other countries of the moderate latitudes normally are proterandrous and their anthers open 2 or 3 days before the silks appear on the same plant. The corn samples brought from the tropical regions of America, according to G. N. Collins' experiments in the United States and to our own experiments made in U. S. S. R., have a more pronounced proterandry which often interferes with normal pollination. Among these samples the silks did not appear until 2 or 3 weeks after the appearance of anthers on the tassels.

On the contrary, in many of the corn samples brought from the large regions of central Asia simultaneous blossoming of the male and female inflorescences and very often even a distinct proterogyny oc-

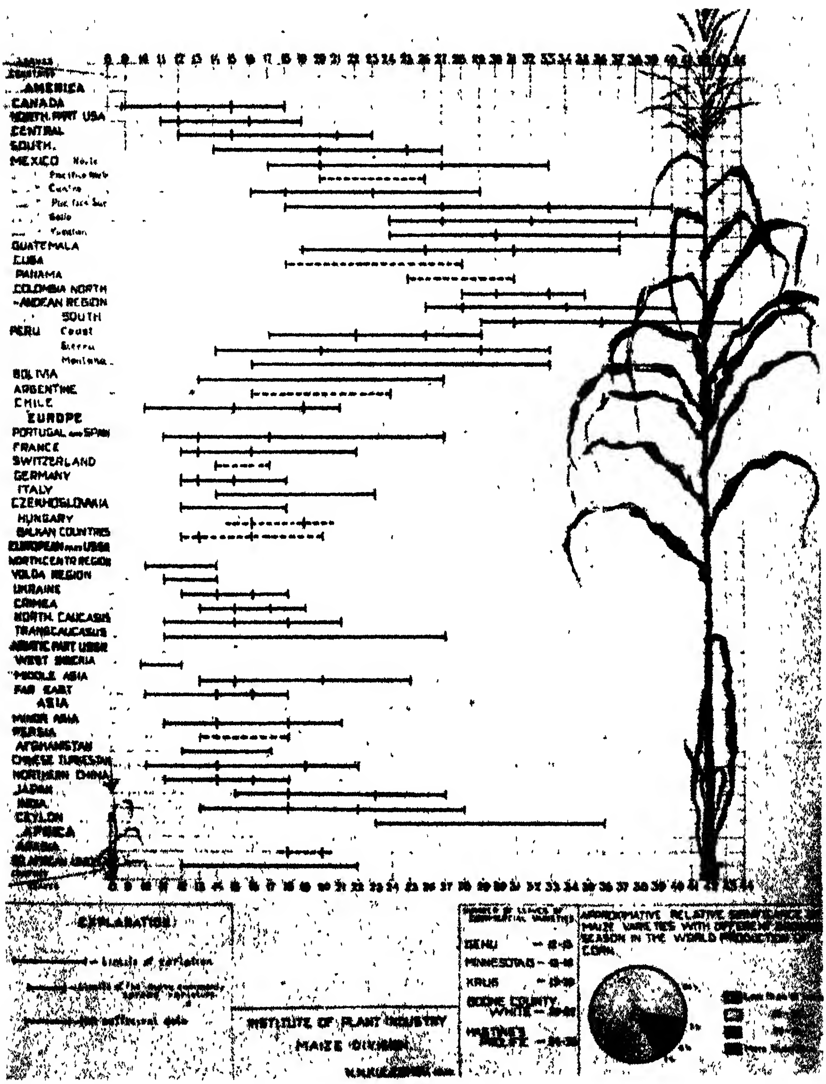

FIG. 1.—Number of leaves as an index to the growing season of maize varieties in different countries.

curred. Collins has described a distinct case of proterogyny in red pop corn, purchased at Granada, Spain, by Walter T. Swingle. Some proterogynous plants often are observed in commercial varieties, but

proterogyny observed in many samples originating from the same geographical region doubtlessly is inherent. This condition as we have found it for the samples from central Asia seemingly has not been described.

A genetic study of the corn blossoming biology has not yet been developed, although under modern methods of corn breeding within selfed lines the biological peculiarities of blossoming have a great practical interest.

HEIGHT OF PLANTS

Generally speaking, the height of the plants in different varieties varies according to the length of the growing season. The extra-early varieties are the smallest (60 to 70 cm), while the latest varieties from Yucatan and Colombia, planted in the region of Sukhum, reach 600 to 700 cm.

Among the exceptions to this general tendency are the samples of central Asia (Turkestan and Persia), as well as those of Transcaucasia (Armenia and Azerbaidjan). There were found very peculiar corn varieties, having a short, solid stalk with thick short internodes. The lower internodes wind up in zigzags, as was described by J. H. Kempton for brachytic plants. In general, these plants doubtlessly have a tendency to brachysm, but genetically they are not identical as the F_1 plants from a cross with Kempton's brachytics were of normal height. Many samples from mid-Asia ripen just as early as the varieties Krug and Leaming (19 to 21 leaves), but have a height of only 100 to 120 cm, although these American varieties attain a height of 250 to 270 cm under similar conditions. Kempton, estimating the physiological and agricultural significance of such a brachytic variety, makes three important comments, as follows:

1. As a general rule, the commercial varieties of corn are taller than is necessary to satisfy the physiological requirement for yield of grain."
2. The plants with a shortened stalk have a much smaller tendency to lodge than the varieties of normal height, especially in regions with irrigated soils.
3. By shortened internodes more nodes are in contact with the soil and develop roots.

All of these advantages, on the whole, are had in the mid-Asian varieties, but in addition they have a normal productivity, which Kempton's brachytics have not. These facts make us attach a great interest to this group of corn varieties for practical breeding as well as for genetic study.

VEGETATIVE TYPES OF THE CORN PLANT

The vegetative parts of the corn plant in all their variability, as presented in our world collection, provide a large quantity of material for study which has hardly been surveyed. The diversities in the plant's height, in the number, length, and breadth of leaves, in the presence or in the absence of anthocyanin, and in the pubescence of the leaf sheath, etc., are innumerable.

Nevertheless, all this immense variability permits of a certain systematizing through a selection of several vegetative types of plant differing from one another not by one but by a whole complex of characters. These types are adapted to definite geographical regions or climatic and soil conditions. The vegetative types described here are of a very generalized character. Among them one can also distinguish subtypes, races, etc. The present article does not go beyond the type specification, as follows:

1. *The northern type.*—Mostly a small plant with a short growing period, having a great tendency to form suckers with ears low on the stalk and with leaf blades developing on the husks. The many suckers, the low ears, and the formation of the leaf blades on the husks create on the lower part of the plant a thick mass of leaves which gives a bushy habit to the whole plant. The upper part of the plant, on the contrary, has very few leaves.

2. *Common type.*—This has a great variety of forms, with different size, diverse numbers of leaves, and with a variation in anthocyanin pigmentation. A proportional disposition of leaves on the stalk, its comparatively large size, and a high ear position, and, in general, a tall slender habit are the characteristics of this type. One can assign to this type most of the American corn varieties, the varieties of the European corn belt, and most of the varieties from Argentina, north Mexico, etc.

3. *The central Mexican type.*—This is characterized by several sharp differences which permitted old authors even to distinguish it as a separate species, *Zea hirta* Bonaf. The distinctive characters of this type are a strongly pubescent leaf sheath with the presence of anthocyanin, feebly developed tassel with a small number of branches, a drooping leaf, superficial rooting which permits severe lodging of the plants of this type, and sharply marked proterandry. In addition to these features, we find indications in the literature of its possessing cold and drought resistance. This type occurs in a very restricted area limited to the central Mexican upland. Corn plants belonging to this type have mostly 17 to 23 leaves.

4. *The Central American type* (Chiapas, part of Yucatan and Guatemala).—This plant reaches a great size, has about 40 leaves, and is about 600 to 700 cm high. It has a strong anthocyanin pigmentation of the leaf sheaths, nearly a normal character of flowering, and very coarse, ligneous husks. Sometimes the leaves are coarse.

5. *The type of Boyaca and Peru.*—The most characteristic features of this type are a very dark, dense anthocyanin pigmentation of the leaf sheaths and of the stalk, a peculiar form of leaf, breaking in the middle of its lower third, very sharp proterandry, and a large tassel with slender branches. Among this type are plants of different vigor, differing markedly in the length of growing season.

6. *The Persian type.*—A short plant with a pronounced tendency to brachytic structure; prominent, short leaves with a strongly developed cuticle, the tassel covered by the upper leaves; the silks concealed in the leaf axil; a proterogynous character of flowering; and an inclination to prolificacy. Its area is central Asia and adjoining Persian Transcaucasian regions. The number of leaves is 13 to 24.

The six types described above, are only an attempt to generalize among the great diversity which we find in the field by observing the plats of corn from the world collection. The inspection of the plats leaves an extraordinary impression of the wonderful plasticity of the corn plant, which, by changing its structure, has responded to the conditions in the different regions where it grows. In addition to the descriptions, we give here some data depicting the quantitative variation in some vegetative characters of the corn plant (averages):

1. Height of the plant 60 to 70 to 650 to 700 cm.
2. Number of leaves on the principal stalk, 8 to 48.
3. Length of leaf, 30 to 152 cm.
4. Breadth of leaf, 4.0 to 15.0 cm.
5. Number of stalks, 1 to 12.

DISPLAY OF RECESSIVE CHARACTERS

Studying the many samples of the world collection of corn, one finds the same characters which have already been studied genetically in samples of quite different geographical origin. In this paper, we refer only to three characters, *viz.*, ligulelessness, discovered by M. I. Khadjinov and B. S. Savrogne from seven quite independent geographical sources (Far East of U. S. S. R. Armenia, North Caucasus, and United States); glossy seedlings, discovered by M. I. Khadjinov in more than 20 samples, including some from U. S. S. R., United States, middle Asia, western Europe, etc.; and ramosa, found in more than 10 samples.

How can one explain the appearance of these characters in different places situated so far one from the other? With respect to them one may use the same phrase, which was used by P. S. Mangelsdorf upon the discovery of waxy seeds on ears of American origin, which previously had not been observed, "It may have arisen as a mutation in very recent years or it may have been carried by the stock as a hidden recessive for centuries." There is considerable interest in clearing up the question, Is it the same gene which has produced in different places these phenotypically homogeneous phenomena or are they genetically heterogeneous?

GEOGRAPHICAL DISTRIBUTION OF SYSTEMATIC CORN GROUPS

The geographical distribution of the following systematic groups over the world presents evidences of regularities which have great interest and require new and supplementary researches:

1. *Zea mays indurata*.. .... flint corn
2. *Zea mays amylacea*................ flour corn
3. *Zea mays indentata*............... dent corn
4. *Zea mays everta*................... pop corn
5. *Zea mays saccharata*.............. sweet corn
6. *Zea mays amyleasaccharata*......... starchy-sugary corn
7. *Zea mays ceratina*................ waxy corn
8. *Zea mays tunicata*................ pod corn

Pod corn is excluded from this account because we have no authentic indication of the practical cultivation of this variety in any definite region. The variety is deprived of a fixed geographical area, but a

spontaneous appearance of pod corn ears has been described in different places.

Surveying the geographical distribution of the remaining seven groups, we first look at their geography in America and then pass to the Old World. As America is the home of corn, the variability of corn in the Old World is secondary and must be observed from the standpoint of facts established for America.

1. Flint corn (*indurata*) is widely distributed within the American continent. Its presence is noted in all regions where maize is cultivated, but its importance among other groups differs in every region. At the northern frontiers of corn culture, the flint varieties are predominant. Farther to the south the importance of this group lessens. In the corn belt of the United States this group plays a very minor rôle. It is also unimportant in north and central Mexico. A marked increase in its importance begins in the southern states of Mexico, and the flint corn groups quite distinctly occupy a dominant place in the countries of Central America (Guatemala, Panama) and in northern Colombia. The islands situated in the Atlantic at the same latitudes also produce mostly flint corn.

Moving further to the south, in the southern regions of Colombia, the influence of the flint groups is considerably smaller. In Peru, one also finds flint corns, but to a very small extent in comparison with what we have seen in the north. More to the south, in Chile, the importance of the flint group rises again, and at the southern corn frontier the flint varieties occupy first place.

Unfortunately, we have no material which could enlighten us as to the question of corn production in the countries situated in the eastern part of South America, except for Argentina and Uruguay. In these countries the flint group is distinctly predominating, especially in its yellow and orange-yellow varieties.

All that was said about the *indurata* group shows that in several American regions we can state the quantitative dominance of the flint group among the varieties of the corn fields. A deeper qualitative research, however, leads us to a definite conclusion that the greatest variability in the characters of the flint group must be attributed to Central America and northern Colombia. The grain and cob pigmentation and the size and shape of the ears are more diverse there than in any other country. This, together with the fact that in these countries we have also a distinct quantitative dominance of the flint group, compels us to pay greater attention to these regions when studying the geographical distribution of the flint corn group. In the Old World, the flint group is of exceptional importance. From the coasts of the Atlantic in Spain and Portugal to the coasts of the Pacific, and also in Japan and the neighboring islands, this group dominates. This fact must be connected with another, that Columbus and his followers, when visiting America, landed in countries where flint corn was grown almost exclusively. Seemingly, the grains of the flint corn were the first grains of this plant which were seen by Europeans.

2. The flour group has a very wide distribution in America. Its northern frontier is only a little south of the limit of corn growing in

general. Having a relatively important place in the corn fields of the Indian tribes in Canada and the northwest of the United States, flour corn almost disappears in the principal corn-growing regions farther to the south. The rôle of this group again rises in the southwestern states of the United States, where one can often observe the drought-resistant varieties of this group on Indian reservations.

In the northern regions of Mexico, the occurrence of the *amylacea* group is very rare. In the central states of Mexico flour corn has more of a place among the aboriginal corn varieties of that region, but the increase in importance is slight. Moving to the south, in the southern districts of Mexico and in Central America, we observe immediately a sharp fall in this group's importance. Its rôle is also small in northern Colombia. The situation changes immediately in the southern districts of Colombia located far from the Pacific in the valley of the Andes. Here the flour corn group is doubtlessly predominant. This predominance continues into Peru, where all other groups are intermingled among the predominating flour varieties. Nearly the same situation may be noted in Bolivia. Analyzing very large collections gathered for our Institute by the expeditions of S. M. Bukassov and S. W. Useptchuk, we come to the conclusion that the greatest diversity in the *amylacea* group occurs in Peru. According to the form and size of the ears and grain, to the form, thickness and pigmentation of the cobs, and to the color of the grain, Peruvian flour corn gives a myriad forms. This diversity occurs also in southern Colombia and Bolivia but never in any other country.

The literature notes the occurrence of flour corn cultivation also in Argentina, but here this group does not play a perceptible rôle either qualitatively or quantitatively.

In the Old World, the flour corn group has a very limited distribution, except for some regions of the U. S. S. R. where the acreage of the Ivory King variety has largely increased during recent years and in the South African republics where flour corn is used by the native population for bread.

The flour corn group was first described in Europe by Bonafous in 1836. Among our collections flour corn varieties come from the Far East of U. S. S. R. in Manchuria, from China, and from Chosen.

3. Passing now to the geographical distribution of the *indentata* group, we notice conditions differing from those in the flour and flint groups. First, such extra-early varieties are not found in the dent as occur in the flour and flint corns. Therefore, the northern frontier of this group is somewhat to the south of that of the first two groups. A little to the south of its northern frontier, the dent group increases considerably in importance and occupies first place. Farther to the south, in the corn belt region, the dent varieties surpass all other groups. In Mexico the dent group also predominates, but in the southern states of Mexico the importance of flint corn increases. In Central America, as has been shown, flint corn predominates and the dent varieties have a very restricted rôle. The dent group in aboriginal culture does not pass into South America. In the rare cases when we found a dent variety in South America we could prove its foreign extraction and its connection with an agricultural college,

experiment station, etc. We are firmly convinced, therefore, that the dent group is organically connected only with the northern half of the American continent. Studying the richness and diversity of dent corn varieties, we conclude that the greatest diversity among the dent varieties must be closely connected with the central and partly with the southern states of Mexico. Nowhere else in the world do we find such diversity of color, form, and size in dent corn.

Indentata occupies a peculiar place in the Old World. Beginning with the sixties of the last century, the dent varieties flowed more and more into the Old World. Transcaucasia and North Caucasus, the Ukraine, the Balkans, Hungaria, and some African regions largely began to cultivate the dent varieties. It is interesting to notice that in many countries (Transcaucasia, the Balkans, Asia Minor), resulting from the hybridization of the new dent varieties with the local flint varieties, a stable semi-dent type was formed which now has become dominant in several regions

4. The pop corns (*everta*), like the dents, do not provide extra-early varieties, hence have not moved to the north. In our Institute's collections we find samples of pop corn gathered in different countries and localities, but nearly everywhere the varieties of this group are only intermingled, and in very small quantity, among the large fields of the other corn groups.

In all the world, one can name only two regions where pop corn forms a considerable part of the field culture. The first is some counties in the states of Iowa and Nebraska where pop corn is produced on a large scale for public consumption throughout the United States, and the second is the state of Mexico and the Federal District of the Mexican Republic. These two regions have fundamental differences. In Iowa and Nebraska, the increase in pop-corn growing is recent and was induced by commercial advantages. In the states of central Mexico, on the other hand, we find the old aboriginal culture of these varieties. Together with a great qualitative rôle of pop corn in this region, we must also note that nowhere else in the world does there exist such a diversity of form and coloring in this group. To this small region one must connect the greatest variability of the group *everta* and also probably its history.

Farther to the south, from Central and South America, we find samples of pop corn, but here also they usually are only incidental intermixtures in the variety masses of other groups.

In the Old World pop corn is known in all countries and regions where it can ripen, but this corn usually is grown only in very small patches.

5. Sweet corn became known to Europeans in America much later than the above-described groups (about 1778–1780). The principal regions of its contemporary culture are the central and northeastern parts of the United States. In the south, little sweet corn is grown, and in the tropics it is nearly absent. In the large collections gathered in Mexico, Central America, and Peru, we have observed sweet corn only once, in two samples from the state of Sinaloa which were called "dulce de Sinaloa." These samples have red grains and a very unique flat form of grain never met in other regions.

In the Old World, in vegetable gardening, the varieties of sweet corn are well known. The first description of sweet corn was made in Europe in 1836 by Bonafous. In 1883, Vilmorin described seven varieties of sweet corn, all with American names. Evidently sweet corn became known only recently in the Old World.

The largest areas occupied now by sweet corn are located in the northeastern part of the United States. Here it was first discovered and here is concentrated the greatest diversity among its varieties. Nevertheless, we must note that sweet corn has undergone such a great change through selection and hybridization with the most diverse varieties of other groups that it is quite impossible to speak about its original variability.

6 In our collections, starchy-sugary corn is represented by 13 samples brought from Peru and by 3 samples from Bolivia Sturtevant, in his classical work, has described only four samples, three of which were received from Mexico and one from Peru. Nowhere in the world, except these two regions, is this group known in practical cultivation The greatest diversity in this corn can be found in Peru (red, white, yellow, and purple grains)

7. The waxy corn, so far as is known, is cultivated only in eastern Asia. It was first described by G N Collins in 1908 in a sample brought from Shanghai. Later he described an assortment of this variety from mountainous Burma Afterwards waxy corn was found in the Philippines (1920).

In 1925–27, we found waxy corn in the regions of Shanghai, northern Manchuria, and the Far East of U. S. S. R. M. I. Khadjinov in 1930 found waxy grains in one sample brought by Dr. Vavilov from western China (Chinese Turkestan). In contrast to these numerous appearances of waxy corn in Asia, only two occurrences of waxy corn in America are recorded, and waxy corn has never been cultivated practically on that continent. We consider the Asiatic origin as more probable for waxy corn. The greatest diversity in its varieties were found in upper Burma.

DISCUSSION OF GEOGRAPHICAL DISTRIBUTION OF CORN GROUPS

On the basis of the preceding data, we can draw the following conclusions:

1 The principal world corn production is provided by three corn groups, *viz.*, dent, flint, and flour These are real field crops. Today, about 97 to 98% of the world acreage of maize is occupied by them. Fourth place is occupied by pop corn which in Central Mexico is one of the principal field corns. Sweet corn occupies fifth place, while the areas under *amyleasaccharata* and *ceratina* are insignificant in the world's corn production.

2. Various facts and their consideration point to basic differences in the geographical distribution of the flint, dent, flour, and pop corns, on the one hand, and the sweet, starchy-sugary, waxy, and tunicata corns, on the other. The first four groups play a large part in corn culture and are zonal groups, having their own botanically determined areas. The last four groups are partly azonal and partly

intrazonal and are nowhere predominant in acreage but are always intermingled with other groups.

3. Geographical regions in which the greatest diversity in the different groups is observed are situated in different places. In general, we can not say in which region one can find the greatest diversity of maize varieties. We can only decide this question separately for the different groups. The greatest variability of the dent and pop corns is still found in Central Mexico; of the flour group in the neighboring regions of Peru and Bolivia; and of the flint group in the south of Mexico, Central America, and northern Colombia.

DIVERSITY WITHIN INDIVIDUAL SYSTEMATIC GROUPS

The above-mentioned facts about geographical distribution and the importance of the varieties of the different systematic groups, as well as the difference in the regions of their greatest variability, lead to the necessity of studying the variability of the maize plant not for the species of *Zea mays* as a whole, but separately for different groups.

Such a study shows that the range in variation in the groups is very different. The diversity of the *saccharata*, *amyleasaccharata*, and *ceratina* groups is very limited (length of growing season, diversity of pigmentation, grain and ear size, and shape).

The *everta* group is considerably richer in all the characters noted, then follow the dent and flint groups. The greatest diversity distinguishes the flour corn which as to grain and cob form and pigmentation includes all the variability of the species *Zea mays* and which appears only partially in the other groups. These conclusions are illustrated in Table 1.

TABLE 1.—*Diversity of some characters of maize plants within the systematic groups.*

Groups	No. of leaves	Length of kernels, mm	Breadth of kernels, mm	Weight of 1,000 kernels, grams
Amylacea	10–44	6–21	5.4–18.0	100–1,200
Indurata	8–42	5–18	4.5–16.0	70–710
Indentata	13–38	9–20	5.0–14.0	100–700
Everta	14–27	2.8–13.0	2.9–7.0	50–220
Saccharata	9–22	5.5–16.0	6.6–13.0	70–300
Amyleasaccharata	28–33	11–18.0	8–9.0	300–550

These facts also allow us to speculate on the evolutionary ages of the systematic corn groups. The absence of their own botanically fixed areas, their lesser variability, and, finally, a whole series of historical considerations, lead us to designate the groups *saccharata*, *amyleasaccharata*, and *ceratina* as being the youngest in point of evolution.

We explain their origin only by mutation to a departure from the normal course of assimilation of the reserve substance to the final state of starch. The exceptional variability of the group *amylacea*, together with many other historical data (Indian reservations, excavations, etc.), allow us to consider that group as the most anciently known corn variety.

All of these problems can not be solved at present, but their study will afford much information on the origin and variability of *Zea mays*.

CONCLUSION

This short sketch on the variability and diversities of maize phenotypes leads us to the conclusion that genetic investigations have not yet exhausted the phenotypical richness in the maize plant. The group of extra-late corn varieties (having over 30 leaves) has been left completely out of the genetic investigation This group is very interesting, because by its distribution it is connected with those centers where occur the greatest variability of characters to be distinguished by the eye Under the covering of dominant characteristics much is left undiscovered that can be ascertained only by genetic analysis. The attention of geneticists and corn breeders should not be limited only to studying known varieties and to the forms which can mature in moderate latitudes, but should include all the diversity of the species partly shown in this paper

THE CONTROL OF BERMUDA GRASS THROUGH THE USE OF CHLORATES[1]

H F MURPHY[2]

In several portions of the southwest, Bermuda grass is about the only grass which can be satisfactorily grown on lawns The limited rainfall and intense sunshine, along with other factors, perhaps tend to be more than the other lawn grasses can withstand. This being the case, and due to the nature of Bermuda grass, this grass may become a pest in gardens and shrubbery. Also, sometimes it gets a fast hold in cultivated fields and as cultivation tends to spread it, due to carrying parts of the grass to new locations, the grass may become a serious pest in such fields The type of rainfall and its distribution in this section is such that during the cultivation period there is sufficient moisture for the loosened grass carried by the cultivator to take hold and grow.

Many investigators recently have studied the control of weeds through the use of chemicals In the summer of 1929, the writer laid off some plats of Bermuda grass for control studies. This grass had been mowed about the last week in May of that year At that time the grass was not very tall and about all that was done in the mowing was that the early developed weeds were cut off and prevented from seeding. The plats were located in a rather low area which was quite fertile. In fact, the area had been left to grow to weeds and grass for some few years preceding the experiment.

On July 15, 1929, 14 plats were laid off. Seven of these were on unmowed grass and seven on mowed grass. The mowed area was cut the day preceding the chemical application. To give an idea of the

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thriftiness of the Bermuda grass, the following figures show the yields of hay per acre on the mowed plats:

Plat No.	Pounds Per Acre*
1	1,900
2	2,550
3	3,100
4	2,450
5	2,100
6	2,500

*Air dried for 1 day with the temperature at 93°F the afternoon of weighing.

The stands were uniform throughout the whole area, both on the mowed and unmowed sections. The reason for the differences in the weight of hay between the mowed plats is accounted for by height of growth rather than by stand differences. Each of the plats contained 1/100 acre. The treatments used on each of the two areas are shown in Table 1.

TABLE 1.—*Plan of treatment for control of Bermuda grass.*

Plat No.	Chemical used	Strength per gallon, lbs.	No. of gallons per acre per application
1	Sodium chlorate	½	100
2	Calcium chlorate	½	100
3	Sodium chlorate	1	100
4	Calcium chlorate	1	100
5	Sodium chlorate	2	100
6	Calcium chlorate	2	100

The first application was made on July 15 and a similar one on September 3. On the latter date very dry soil conditions prevailed. Previous to making the application on September 3 the following notes were taken:

"All treatments prevented head formation on the unmowed plats. On the mowed plats the heavy applications of 2 pounds per gallon prevented head formation. The ½-pound and 1-pound applications did not prevent head formation completely on the mowed plats. The 2-pound applications of either chemical, both on the mowed and unmowed areas, caused considerable dying of the Bermuda, but not enough to constitute control. Approximately 60% of the tops of the plants were dead on the unmowed 2-pound sodium chlorate treated plat, while about 35% of the tops were dead due to a like treatment of calcium chlorate. Considering the same ratio of treatment on the mowed grass, sodium chlorate showed 30% of tops dead, while calcium chlorate showed approximately 25%. While ½-pound and 1-pound applications of either chemical on the mowed area hindered head formation to some extent, yet the tops were not killed, all of these plats having a good green color."

Early in the spring of 1930, about April 1, practically no difference could be detected between the heavily treated plats of either sodium or calcium chlorate on either of the two areas; although it seemed

that if anything, the heavy calcium chlorate treatment was a little better in the mowed area. Both were practically free from any Bermuda grass top growth at that time. On the unmowed area no difference could be detected, there being no top growth of grass showing. Upon examination the root system appeared almost completely dead on all four of the plats. The plats were not dug up, however, for complete examination. Only partial control appeared on all of the other treated plats. No difference could be detected between the sodium chlorate and calcium chlorate treated plats, either on the mowed or unmowed grass, when the chemicals had been used at the light rate of application. For the intermediate rate of application, the sodium chlorate plat on the mowed area appeared to give considerably better control than any of the other intermediate treatments. It appeared to be nearly free from Bermuda.

On May 1 a few weak plants were found on the heavily treated plats on both the mowed and unmowed areas. There was no appreciable difference noted between the two chemicals at this rate of use at that time

On May 31 it was noted that there were a few more Bermuda plants on the heavily treated calcium chlorate plats than on the similarly treated sodium chlorate plats; both, however, were good controls.

On June 10, after growth was well started and after the usual spring rains, a thorough examination was made of the various plats to determine the number of plants per square foot. The results are given in Table 2.

While 100 pounds of either sodium or calcium chlorate reduced the stand of Bermuda grass considerably, on account of the nature of the grass, the treatments did not give control. Such reductions would soon be unnoticed with this grass.

On the mowed area, 200 pounds of sodium chlorate showed up exceptionally well. The other intermediate treatments were not nearly so good. This plat seemed to be quite similar to the heavily treated plats, and upon examination, grass counts revealed that it was (Table 2).

TABLE 2.—*Number of Bermuda grass plants per square foot on June 10.**

Chemical	Rate per acre, lbs., divided into two applications	Number of plants per sq. ft.	
		Mowed area	Unmowed area
Sodium Chlorate	100	25	28
Calcium Chlorate	100	27	25
Sodium Chlorate....	200	2	14
Calcium Chlorate.	200	21	16
Sodium Chlorate......	400	0.65	0.55
Calcium Chlorate......	400	2	2

*The untreated area showed 46 plants per square foot.

On May 1, 1930, one-half of each of the plats was plowed approximately 6 inches deep, worked down with a disk, and drilled into Sumac cane at a heavy rate, using a grain drill. The cane made a

very excellent growth on all of the plats. An examination of the cane-seeded areas in the fall of 1930 indicated few Bermuda plants on any of the plats. The same areas were plowed and seeded to cane again in 1931. In the late spring of 1932, after all vegetation had started, examination of the cane-seeded area indicated that there was a complete control of Bermuda grass on all of the plats, not a single Bermuda plant being found in the area. That portion of the chemically treated plats not sown to cane had by this time become reinfested with Bermuda, due to the runners entering the plats from the outside and re-establishing the stand.

The entire area of Bermuda sod and the controlled area were burned off in May, 1932, plowed approximately 6 inches deep, and drilled into Sumac cane. On July 25, 1932, there was from 50 to 75% kill in the Bermuda sod planted area. Where the stand of cane was thickest and on the better soil no Bermuda could be found, but where the cane stand was thin or where the soil was lacking in fertility and hence a poorer growth of cane, the Bermuda was competing rather well with the cane. On the best soil the cane was about 4 feet tall and was an excellent shade crop.

AFTER-EFFECTS OF CHLORATE TREATMENT ON GROWTH

In 1928, the writer conducted an experiment using various chemicals on the control of bindweed. Two applications of sodium chlorate were made each at the rate of 100 pounds per acre sprayed on the bindweed by dissolving 1 pound of chemical in 1 gallon of water. The first application was made in July and the second in September of that year. The following spring oats were seeded on the area. The oats came up to a good stand but in a few days practically died out and what few plants survived never amounted to much. They were much dwarfed, yellow throughout their growth, and only a few plants came out in head and produced seed. In the spring of 1930, the land was again planted to oats, but no effect of the chlorate could be observed. The oats were uniform in appearance on both treated and untreated plats at harvest time.

One-half of each of the Bermuda plats mentioned above was plowed about 6 inches deep on May 1, 1930, and drilled into cane. No appreciable difference could be noted between the growth of cane for the various treatments on June 10, although the heavily treated plats showed a slightly depressed growth and were slightly yellow.

SUMMARY

Bermuda grass can be controlled through the use of chemicals. However, the rate of application and cost is such that sodium chlorate or calcium chlorate can only be recommended for patchwork control or for control along garden and shrubbery borders.

The use of either of the chemicals at the rate of 100 pounds per acre, either as a single application or when applied as two applications at an interval of about 1½ months apart, did not give a desirable control at all.

Very good control was secured on both mowed and unmowed grass from the use of either chemical when applied in two applications

1½ months apart, from July 15 to September 3, each application being made at the rate of 200 pounds per acre.

The use of sowed cane on weakened Bermuda sod proved to be a good method of control where larger areas were involved. For large areas, shade crops are to be recommended in Bermuda grass control.

AGRONOMIC AFFAIRS

MEETING OF THE AMERICAN SOIL SURVEY ASSOCIATION

The American Soil Survey Association will hold its fourteenth annual meeting at the Hotel Stevens, Chicago, Illinois, on November 15 and 16, 1933 Sessions on November 15 will be chiefly devoted to soil cartography, horizon criteria, soil structure, and soil acidity. A banquet on November 15 will be followed by an illustrated lecture by Dr. E. N. Transeau, Ohio State University, on the ecology of the Ohio Valley.

Sessions on November 16 will dovetail those of the Soils Section, American Society of Agronomy, and will be devoted to forest soils, edaphic relationships, and the timely subject of land use. Certain papers on soil physics and chemistry will be presented jointly with the Soils Section of the American Society of Agronomy on November 17.

THE ANNUAL MEETING OF THE SOCIETY, NOV. 16 AND 17

The twenty-sixth annual meeting of the American Society of Agronomy will be held November 16 and 17 in the Stevens Hotel, Chicago. The meeting will consist of a half-day session devoted to a general program of interest to all agronomists and of meetings of the Soils and Crops Sections of the Society.

Cooperating with the Land Grant College Association and the American Soil Survey Association, the Society has made arrangements for reduced railroad fares to Chicago on the certificate plan. Those who attend the meeting should, therefore, purchase a one-way ticket to Chicago and at the same time obtain a certificate from their local ticket agent. The validation of this certificate at the registration desk at the meeting will enable the holder to purchase a return ticket at one-third the full rate.

The program for the general session of the Society, arranged by President M. A. McCall, provides for a discussion of the regional correlation of agronomic research. The subject will be discussed by L. E. Call of Kansas from the standpoint of the experiment station director, by H. K. Hayes of Minnesota from the standpoint of the crops investigator, and by R. M. Salter of Ohio from the standpoint of the soils investigator.

The first session of the Crops Section to be held on Thursday, November 16, will be devoted to a symposium on "The Application of Statistical Methods to Agronomic Research," with M. T. Jenkins of Iowa, Chairman of the Section, as Leader. Those participating in the symposium and their topics are as follows: "Plat arrangement in Soils Experiments," R. M. Salter and J. T. McClure; "The Applica-

tion of the Analysis of Variance to Agronomic Experiments," F. R. Immer; "The Relation of Plat Size, Shape, and Number of Replications to Precision," A. A. Bryan; and "Why Use Statistics?" S. C. Salmon. The two sessions of this Section on Friday will be devoted to the presentation of short papers reporting the results of recent original research.

The program for the Soils Section, Richard Bradfield of Ohio, Chairman, is being organized on a sub-sectional basis, with a specialist in each field in charge, as follows: Soil Biology, E. B. Fred of Wisconsin; Soil Fertility, C. E. Millar of Michigan; Soil Chemistry, G. D. Scarseth of Alabama; and Soil Physics, H. G. Byers of the U. S. Dept. of Agriculture. Each sub-section will devote one session to technical subjects of interest to that specialized group, while subjects of more general interest will be presented before joint sessions of the groups interested.

It is planned to publish the complete soils programs of both the Soils Section of the Society and of the American Soil Survey Association in the programs of both organizations. This coordinated program will be presented in three days (November 15, 16, and 17) instead of four as heretofore. The first day will be devoted to subjects of primary interest to those engaged in soil classification work, the second day will be devoted largely to subjects of interest to the membership of both groups, and the third day to subjects of more general agronomic interest.

An important meeting of all the American members of the International Society of Soil Science will be held on November 16 to consider the formation and functions of an American Section of the International Society. This meeting is set for the day on which both the American Society of Agronomy and American Soil Survey Association are in session in order that members of the International Society from both organizations may attend without inconvenience.

RECOMMENDATIONS FOR 1934 WITH REFERENCE TO THE FERTILIZATION OF FLUE-CURED, SUN-CURED, AND SHIPPING TOBACCO GROWN ON AVERAGE SOILS IN VIRGINIA, NORTH CAROLINA, SOUTH CAROLINA, AND GEORGIA

I. FERTILIZERS FOR BRIGHT FLUE-CURED TOBACCO

1. Analyses of Mixtures and Rates of Applications:

(1) *For heavy or more productive soils.*—Three per cent total nitrogen, 10% available phosphoric acid, and 6% potash. To be applied at the rates of 800 to 1,000 pounds to the acre.

(2) *For light or less productive soils.*—Three per cent total nitrogen, 8% available phosphoric acid, and 6% potash. To be applied at the rates of 1,000 to 1,200 pounds to the acre.

Note 1.—Where high topping is practiced and heavy yields are expected, the potash content may be increased to 8 to 10 % in a 1,000-pound application per acre with profitable results.

Note 2.—The above analyses may be modified, provided the given ratios are maintained and the recommended sources of plant food are used.

2. For Control of "Sand-Drown" (Magnesia Hunger):

It is recommended that fertilizers carry 2% magnesia (MgO). at least one-half of which shall be derived from water-soluble materials.

3. Chlorine:

Available experimental data from bright tobacco sections of Virginia, North Carolina, South Carolina, and Georgia show that a small quantity of chlorine in the tobacco fertilizer increases the acre value of the crop. Experiments have shown, however, that an excessive amount of chlorine in fertilizers used for tobacco injures its growth and reduces quality, producing a thick brittle leaf, which when cured, becomes thin, soggy, and dull in color. It also has an unfavorable effect upon the burning quality of the cured leaf. It is recommended, therefore, that fertilizers be compounded in such proportions that the fertilizer mixtures shall contain 2% chlorine.

4. Sulfur:

Since experiments show that maturity is delayed and the colors of the cured leaves have a tendency to be red when large quantities of sulfur are included in the fertilizer mixtures, it is recommended that fertilizers for bright tobacco be formulated so as to contain a minimum quantity of sulfur

5. Sources of Plant Food Constituents:

(1) *Nitrogen.*—One-half of the nitrogen should be derived from high-grade organic materials of plant or animal origin, such as cottonseed meal, fish scrap, and high-grade tankage. (Fertilizers that are claimed to be made according to the recommended formula should contain not less than 50% of the total nitrogen in organic form and not less than 40% of the total nitrogen should be water insoluble.) At least one-fourth of the total nitrogen should be derived from nitrate of soda and / or nitrate of potash. The remainder should be derived from such materials as urea and / or standard inorganic sources of nitrogen.

(2) *Phosphoric acid.*—To be derived from superphosphate, double superphosphate, and / or dicalcium phosphate.

(3) *Potash.*—To be derived from any source of available potash, provided the chlorine content of the mixed fertilizers so compounded does not exceed 2%. If tobacco by-products are used as a source of potash, these must be sterilized to guard against disease.

II. FERTILIZERS FOR DARK TOBACCO (SUN-CURED AND SHIPPING)

1. Analysis of Mixtures:

Use 8% available phosphoric acid, 3% nitrogen, and 3% potash.

Note 3.—The above analysis may be modified provided the given ratios are maintained and the recommended sources of plant food materials are used.

2. Amount of Fertilizers:

Use 600 to 1,000 pounds per acre in the drill thoroughly mixed with the soil about 10 days prior to transplanting. If the analysis is modified as provided for in Note 3, use equivalent amounts of plant food materials per acre.

3. Source of Plant Food Constituents:

(1) *Phosphoric acid.*—To be derived from superphosphate.

(2) *Potash.*—To be derived from any source of available potash, provided the chlorine content of the mixed fertilizer so compounded does not exceed 2%. If tobacco by-products are used as a source of potash, these should be sterilized to guard against spread of diseases.

(3) *Nitrogen.*—One-half of the nitrogen should be derived from high-grade organic materials of plant or animal origin, such as cottonseed meal, fish scrap, and high grade tankage. (Fertilizers that are claimed to be made according to the recommended formulas should contain not less than 50% of the total nitrogen in organic form and not less than 40% of the total nitrogen should be water insoluble.) At least one-fourth of the total nitrogen should be derived from nitrate of soda and / or nitrate of potash. The remainder should be derived from such materials as urea and / or standard inorganic sources of nitrogen.

III. FERTILIZERS FOR PLANT BEDS

Injury due to excess of chlorine has been widely observed in tobacco plant beds. Since fertilizers are applied to plant beds in relatively large quantities, even a small percentage of chlorine in the fertilizers may cause plant-bed injury. It is recommended, therefore, that only such materials as are practically free of chlorides be used for making plant-bed fertilizers. It is recommended, too, that a fertilizer containing 8% phosphoric acid, 4% nitrogen, and 3% potash from the same sources as recommended under Section 1, Sub-section 5, be used, except that all potash is to be derived from high-grade sulfate of potash and / or sulfate of potash-magnesia. The addition of 1% available magnesia (MgO) will be beneficial in certain cases and its inclusion is generally to be recommended.

Committee:

C. B. Williams, *Chairman*, North Carolina
T. B. Hutcheson, *Secretary*, Virginia
W. W. Garner, Bureau of Plant Industry
E. E. Clayton, Bureau of Plant Industry
J. E. McMurtrey, Bureau of Plant Industry
T. L. Copley, Virginia
H. P. Cooper, South Carolina
H. R. McGee, South Carolina
E. Y. Floyd, North Carolina
R. F. Poole, North Carolina
L. G. Willis, North Carolina
E. G. Moss, North Carolina
E. C. Westbrook, Georgia
J. M. Carr, Georgia
W. M. Lunn, South Carolina

September 1, 1933.

RECOMMENDATIONS DEALING WITH DOWNY MILDEW OR BLUE MOLD DISEASE OF TOBACCO

This disease is caused by a fungus which spreads from plant to plant and bed to bed by the spores produced on the under leaf surfaces. These spores are very light and are easily carried by air currents or by men. Since the spores produced during one night are practically all dead by noon of the day following, it is advised that during the early stages of disease attack, when the infection is present in only a few spots, the chances of disease spread be reduced by working in the beds during the afternoon.

Beds in some locations are more severely attacked than in others, hence it is advisable to sow several beds. Generally beds in warm sunny locations suffer the least from the disease, and the plants in such beds make the most rapid recovery.

Early sowing is recommended because large plants are not injured as severely as small plants and recover more quickly.

Thin stands give stronger plants which are better able to withstand the disease.

No fertilizer treatment will control this disease.

Sometime after the disease makes its appearance in the bed, there follows a period of severe disease attack. This period is usually limited to 3 to 4 days, after which plants begin to recover. During the recovery period every effort should be made to provide good growing conditions. If the soil is dry the plants should be watered. Usually the plants will not require fertilization at this time, but in cases where there is distinct evidence of nitrogen shortage one or two applications of nitrate of soda may be made at the rate of not over 2 pounds in 100 gallons of water to 100 square yards of bed. Excessive treatments of any sort will cause great injury by checking the plants and retarding recovery.

With respect to transplanting, it is advisable when possible to get the plants into the field in advance of disease attack. Plants should not be transplanted during the period that the disease is most severe. Plants that have been attacked by this disease are often in a weakened condition and should receive extra care in transplanting.

At the present time spraying is not recommended for the control of this disease.

While the above recommendations will be of considerable aid to growers, it is to be emphasized that more effective measures for controlling this disease must be worked out.

Subcommittee of Plant Pathologists of the Southeastern Tobacco Research Committee:

E. E. Clayton, U. S. Dept. of Agriculture
R. G. Henderson, Virginia
R. F. Poole, North Carolina

September 1, 1933.

JOURNAL

OF THE

American Society of Agronomy

VOL. 25 NOVEMBER, 1933 NO. 11

CHLOROPHYLL CONTENT AS AN INDEX OF THE PRODUCTIVE CAPACITY OF SELFED LINES OF CORN AND THEIR HYBRIDS[1]

HOWARD B. SPRAGUE and NORMAN CURTIS[2]

The relations between chlorophyll content, photosynthesis, and growth are of major interest to the plant scientist. The synthesis of foods in the green tissues of plants is of fundamental importance, for from such synthesis comes the food and likewise the energy for practically all forms of life. An understanding of the problems relating to the manufacture of foods in crop plants is necessary for the effective utilization of our plant resources.

The accumulation of knowledge concerning synthesis of organic materials began about 150 years ago, and the accretion has been gradual throughout the ensuing period. It was not until the first two decades of the present century, however, that the plastid pigments concerned with photosynthesis were isolated and quantitative methods of measuring the pigments were devised by Willstätter and his co-workers. Comprehensive reviews of the literature on photosynthesis have been prepared by Spoehr (6)[3] and by Stiles (10). The excellent monograph on chlorophyll by Willstätter and Stoll (11) has been translated into English by Schertz and Merz, thus facilitating the use of this information.

Two groups of factors must be considered in studies of photosynthesis, i.e., external and internal. The external or environmental group of factors includes quality, intensity, and duration of light, temperature, and moisture; oxygen and carbon dioxide supply; and the supply of nitrogen and minerals from the soil. Among the internal group of factors, such as the number, shape, and size of stomata; the structure of leaf tissues concerned with gas exchange; the absorption and translocation of water, the assimilation of nitrogen and minerals essential for the normal activities of living cells; the trans-

[1]Contribution from Department of Agronomy, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Journal series paper. Received for publication January 16, 1933.

[2]Agronomist and Research Assistant in Agronomy, respectively.

[3]Reference by number is to "Literature Cited," p. 723.

location of elaborated foods; and respiration, are all of importance. However, the quantity of chlorophyll and its effectiveness in utilizing light, carbon dioxide, and water for synthesis have even greater significance. Irrespective of the efficiency with which the various tissues and organs of the plant may function, a deficient supply of chlorophyll or its inefficient operation will limit the quantity of food synthesized, and thereby, the growth made.

Obviously, any of the many factors entering into the synthesis of food may become the limiting one, depending on its intensity. The relative importance of each factor has received some attention from research workers. The quantitative relations between chlorophyll, synthesis of foods, and plant growth have been investigated only since the development by Willstatter and his colleagues (11) of methods for the extraction, purification, and measurement of the plastid pigments. Schertz (5) recently presented a modification of Willstatter's method for extracting and separating the various plastid pigments suitable for use with fresh green tissues. Convenient methods of estimating the quantity of chlorophyll, carotin, and xanthophyll in solutions have been proposed and used by Guthrie (1), Sprague (7), and Sprague and Troxler (9)

With regard to cholrophyll, the agronomist is chiefly interested in determining whether beneficial systems of soil treatment operate by reason of their direct or indirect effect on photosynthesis, and if the inherent chlorophyll content of a particular variety or strain limits the ability of the plant to utilize the materials available for synthesis. The task of selecting superior strains of crops would be greatly simplified if the respective chlorophyll contents could serve as an index of their productive capacities.

Sprague and Shive (8) reported a significant relation between chlorophyll concentration and the ability of certain strains of corn to synthesize dry matter under controlled conditions. The strains observed were apparently normal in color but differed in the concentration of green pigment. There was a significant correlation between the total green pigment per plant and yield of dry matter in the tops. Since chlorophyll is essential for photosynthesis, the conclusion was drawn that increased quantity of chlorophyll was responsible for much of the improvement noted in total dry matter produced.

The experiments cited above (8) included but five different strains of corn and covered only the period from germination to tasseling. Consequently, they did not prove the existence of similar relations for mature plants of all strains. Since the essence of modern breeding methods for corn is the selection of vigorous selfed strains, followed by hybridization, any reliable aid in the prediction of the productivity of F_1 hybrids would eliminate part of the tedious and time-consuming testing now required. The relation between visual estimates of depth of green color in leaves of selfed lines and their yielding ability noted by Jenkins (2) substantiates the belief that concentration of chlorophyll may be a valuable index for eliminating the non-productive selfed lines without actually making hybrids and testing them in the field.

METHOD STUDY

To facilitate extensive studies on chlorophyll content of corn plants, it was necessary to devise simple, rapid, and accurate methods of such a character that the plants could complete growth and mature normally after being sampled. Estimates of leaf area of corn plants have been made for many years by means of Montgomery's (3) formula, *viz.*, leaf blade expanse equals length x width at the widest place on the leaf x 0 75. No accurate proof of the reliability of this formula was found in the literature, and accordingly a test was conducted on 50 leaves from several plants All green leaves on each plant were used, the browned areas being rejected on leaves that were only partly green. Each leaf was blue-printed and the area determined from the outline with a planimeter. Leaf areas thus obtained were then compared with the area calculated from leaf measurements by the formula The results are indicated in Table 1

TABLE 1 *Estimating the area of maize leaf blades by the use of Montgomery's formula as compared with planimeter readings of blue prints of leaf outlines*

	Leaf area by Montgomery formula, sq cm *	Leaf area by planimeter readings, sq cm *
Mean for 50 leaves	330 8	329 5
Standard deviation	160 0	163 2

*Mean difference between two measurements – 18 4 sq cm or 0 56% of the mean planimeter readings Correlation coefficient between readings for the two methods, 970 ± 040

The mean leaf area for 50 determinations was not appreciably affected by the method used The accuracy of the two methods as measured by their respective standard deviations is essentially equal The mean difference of the two methods for the entire 50 leaves was only 18 4 sq. cm , or 0.56% of the mean planimeter reading. The close correspondence in leaf areas by the two methods is shown by the very high correlation coefficient of .970±.040.

Determinations were made of the chloroplast pigment contents of each green leaf on several plants as a guide to a sampling method which would permit pigment estimation without interfering with normal maturation The plants were chosen from different strains and hybrids to insure observations on the general trend of conditions in apparently normal specimens Three of the plants at the dough stage of maturity bore 9 green leaves each and two bore 10 such leaves The detailed results are shown in Table 2.

Chlorophyll concentration measured in terms of milligrams of pigment per 100 sq. cm. of leaf area decreased rather regularly from the uppermost to the lowest leaf of the plant The concentration in the middle leaf was nearly identical with the average for the entire plant. Since the total chlorophyll in each leaf is determined by the product of the area and the concentration of chlorophyll, the maximum chlorophyll per leaf occurred in the middle leaf or leaves.

Carotin was distributed in the leaves in much the same manner as chlorophyll, although the trend was somewhat less regular. Xantho-

phyll concentration was generally greater in the upper leaves, but the values were erratic and little significance could be attached to estimates of this pigment.

On the basis of these results it seemed reasonable to assume that the middle leaf or leaves might be selected as representative of the

TABLE 2.—*The distribution of chloroplast pigments in the leaf blades of normal maize plants.**

Leaf No.	Area of leaf, sq. cm.	Mgms. of chlorophyll		Mgms. of carotin		Mgms. of xanthophyll	
		Per 100 sq. cm. of leaf	Total for leaf	Per 100 sq. cm. of leaf	Total for leaf	Per 100 sq. cm. of leaf	Total for leaf
Average for 3 Plants With 9 Green Leaves Each							
1 (top)	108.7	6.59	7.16	0.190	0.207	0.099	0.121
2	229.9	4.82	11.09	0.157	0.360	0.098	0.260
3	306.2	5.16	15.79	0.170	0.520	0.034	0.100
4	410.0	4.37	17.91	0.157	0.642	0.028	0.109
5	455.4	3.91	17.79	0.148	0.675	0.028	0.134
6 (ear)	465.4	4.14	19.27	0.143	0.664	0.032	0.157
7	478.1	3.11	14.88	0.136	0.651	0.025	0.129
8	358.6	3.24	11 63	0.129	0.463	0 032	0.114
9 (bottom)	155.0	2.98	4.62	0.095	0.148	0.048	0.077
Entire plant	2,967.3	4.05	120.14	0.146	4.330	0.0404	1.199
Average for 2 Plants With 10 Green Leaves Each							
1 (top)	114.8	4.06	4.66	0.152	0.174	0.055	0.062
2	247.4	3.25	8.03	0.141	0.348	0.044	0 117
3	351.4	3.75	13.19	0.142	0.499	0.040	0.126
4	467.5	3.18	14.88	0.116	0.543	0.057	0.216
5	489.9	2.95	14.45	0.131	0.640	0.033	0.137
6 (ear)	521.1	2.99	15.60	0.115	0.599	0.040	0.187
7	540.7	2.31	12.53	0.091	0.492	0.028	0.145
8	378.2	2.42	9.17	0.099	0.375	0.041	0.149
9	200.6	2.77	5.55	0.102	0.205	0.034	0.070
10 (bottom)	79.5	2.08	1.65	0.107	0.085	0.038	0.030
Entire plant	3,391.1	2.94	99.71	0.117	3.960	0.0366	1.241

*Entire leaf blades analyzed when ears were in early dough stage.

average chlorophyll concentration in all leaves. With an estimate of the total area of green leaves by the formula method, the total chlorophyll per plant may be calculated from the known concentration of the leaf pigment. Estimates on the chlorophyll content of plants made by the foregoing method in comparison with complete analyses of all leaves are given in Table 3. The several plants differed greatly, both in concentration of chlorophyll and in total pigment content, the latter ranging from 87.56 mgms. for plant 2 to 172.54 mgms. for plant 5. Nevertheless, the differences observed between the estimated and actual chlorophyll were small. The average difference for the five plants tested amounted to 2.46% of the value shown by complete analysis, a difference which is within the limit of experimental error for this type of determination.

The procedure used in estimating chlorophyll content of plants proved to be equally valuable for carotin. The errors between values obtained by actual analysis and those derived from using the concentration in the middle leaf or leaves as an index, in combination with area of green leaves per plant, differed by only 2.66% on the average. Estimates of xanthophyll by this method fluctuated too widely to attach significance to such values.

TABLE 3.—*A comparison of the chloroplast pigment content of the leaves of maize as measured by analyses of all leaves and of the middle leaf or leaves as an index of the whole plant.*

Plant No.	Total per plant: By complete analysis, mgms.	Total per plant: Estimate based on middle leaf or leaves, mgms.	Difference, mgms.	Per 100 sq. cm. of leaf: Average for plant, mgms.	Per 100 sq. cm. of leaf: In middle leaf or leaves, mgms.	Difference, mgms.
			Chlorophyll			
1	108.30	110.18	+1.88	2.64	2.69	+0.05
2	87.56	81.80	−5.76	3.76	3.51	−0.25
3	91.16	90.80	−0.36	3.39	3.38	−0.01
4	172.54	172.10	−0.44	4.66	4.65	−0.01
5	100.34	95.01	−5.33	3.41	3.31	−0.10
Mean	111.98	109.98	−2.75 =2.46%	3.57	3.51	−0.084
			Carotin			
1	4.850	5.284	+0.434	0.118	0.129	+0.009
2	3.296	3.333	+0.037	0.141	0.143	+0.002
3	3.076	3.036	−0.040	0.115	0.113	−0.002
4	6.370	6.329	−0.041	0.172	0.171	−0.001
5	3.327	3.559	+0.232	0.116	0.124	+0.008
Mean	4.184	4.308	+0.157 =2.66%	0.132	0.136	−0.0044
			Xanthophyll			
1	1.167	1.106	−0.061	0.0285	0.0270	−0.0015
2	0.438	0.303	−0.135	0.0188	0.0130	−0.0058
3	1.315	1.075	−0.240	0.0490	0.0400	−0.0090
4	1.796	1.332	−0.464	0.0486	0.0360	−0.0126
5	1.363	1.005	−0.358	0.0475	0.0350	−0.0125
Mean	1.216	0.964	−0.252 =20.7%	0.0385	0.0302	−0.0083

A great saving in labor is obtained from the use of the estimate method, since a full working day is required for the analysis of 10 to 12 samples. Thus, the determination of pigment for the individual leaves of single plants means a total of 10 days for 10 plants, whereas the estimate method requiring analysis of only one representative leaf for each plant, allows the pigment analysis of at least 10 plants in 1 day.

The use of a Ganong leaf punch further reduced the labor of the analytical work. This instrument, which cuts circles of tissue 1 sq. cm.

in size, provided representative samples of the leaf. Samples obtained in this manner required less labor and chemicals for analysis because of the smaller volume of tissue used. Of still greater importance is the fact that this system of sampling may be applied to full-grown plants without disturbing maturation. Estimates of leaf area by the formula method may also be made from plants in the field without injury, and total pigment content may then be calculated. With this technic established, the study of chlorophyll content of inbred strains as an index of the productivity of their hybrids was begun.

EXPERIMENTAL PROCEDURE

An experiment was conducted in 1930 to determine differences in chlorophyll content and yields of selfed lines of corn, and the relations existing between such lines and their first generation hybrids. Twelve selfed strains were chosen on the basis of depth of greenness noted in the summer of 1929. Three of the inbred lines were graded as light green, five as medium green, three as dark green, and one as very dark green. The appearance of the selfed strains indicated no abnormality in the distribution or quantity of pigment in the leaves. Eighteen first generation hybrids involving the 12 selfed strains were selected to include all types of combinations of greenness in the parental strains

The test field varied from loam to sandy loam in texture, and had been uniformly cropped for several years previously. A grass sod was plowed under in the fall of 1929, and lime was incorporated to correct excessive soil acidity. A 4 8-4 fertilizer was applied with a grain drill at a 400-pound rate prior to planting. Space was available for two series of plats in which random distribution of strains was used. The individual plats were five hills long and four hills wide in the first series and four hills by four hills in the second, with hills spaced 3½ by 3½ ft Each strain and hybrid was planted thickly May 17 and thinned June 12 to produce a perfect stand of three plants per hill.

Pigment determinations were made during late August and early September on leaf samples from plants in the soft dough stage of kernel development. A considerable range in time of ripening for the several strains and hybrids permitted determinations of chlorophyll at approximately the same stage of maturity. The "ear" leaf of all plants of each strain, excepting those in the border hills of the plat, were sampled with a Ganong leaf punch, thus providing 18 discs 1 sq. cm. in diameter from 18 plants in the first series and 12 discs from 12 plants in the second series of plats for separate pigment determinations. In general, values for pigment concentration of the same strain in the two series were in close agreement.

Leaf samples were gathered in early morning and the chlorophyll analysis completed the same day to prevent decomposition of the pigment. Willstätter's method for extraction and separation of chlorophyll was followed with Schertz's (5) modification, except for the substitution of petrol ether for di-ethyl ether. This substitution simplifies the procedure and does not interfere with chlorophyll readings if the aqueous solutions of chlorophyllins are filtered through

hardened filter paper prior to comparison with the color standard in the colorimeter. Evaluations were made in terms of the color standard reported by Sprague and Troxler (9).

The crop was harvested immediately after ripening, both stover and ears were carefully air dried in a drying shed, and the weights recorded. All border hills of each plat were discarded in harvesting,

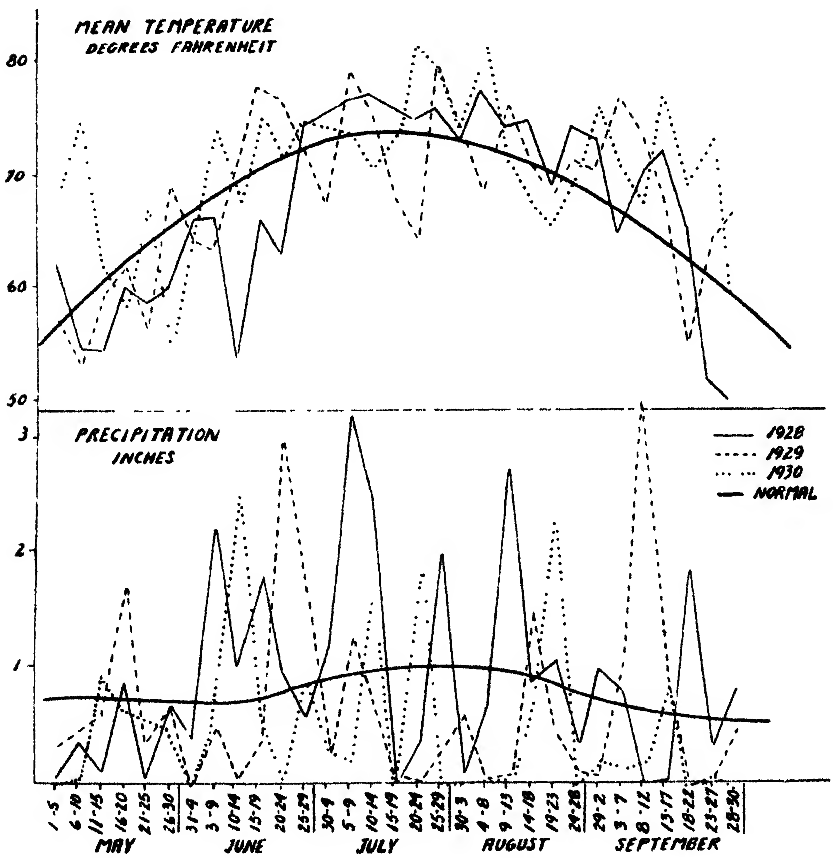

FIG. 1.—Rainfall and mean temperatures by 5-day periods at New Brunswick, N. J., during the growing seasons of 1928, 1929, and 1930.

leaving a total of 18 plants from the first series and 12 from the second for yield determinations of each strain or hybrid.

The season of 1930 was rather unfavorable for corn as a result of unusually dry hot weather between July 20 and August 15 (Fig 1), which was the period of pollination and early kernel formation. The earlier portion of the season was favorable for growth and a vigorous development of leaves and stalks occurred, accentuating the later moisture shortage by heavy transpiration losses. The effect of the drought was most pronounced on grain yields. Thus, in a neighboring field where corn is grown continuously, the shelled grain made up

35.1% of the total yield of dry matter in 1928, 30.9% in 1929, and only 22.8% in 1930.

The influence of the unusual drought was more marked on certain strains and hybrids than on others. Strain B41 was particularly susceptible to moisture shortage. The uncommon weather disturbed the relations normally observed between the various plant characters, and this fact must be taken into account in interpretation of the results.

EXPERIMENTAL RESULTS

The chlorophyll concentration of the 12 inbred lines varied from 11.3 mgms. per 100 sq. cm. of leaf to 5.14 mgms., as indicated in Table 4. The actual pigment content of the darker strains was fairly well correlated with the visual color classification made in 1929, although some differences occurred with the lighter strains. In certain instances the lack of correlation noted may have been due to the difference in response to the drier weather experienced in 1930, but in major part such disagreement was doubtless caused by inability to distinguish with the naked eye minor differences in chlorophyll concentration.

TABLE 4.—*Chlorophyll content of leaves, leaf area, and yield of 12 inbred strains of corn, season of 1930.*

Inbred strains	Visual color classification in 1929, greenness	Chlorophyll concentration per 100 sq. cm. of leaf blade 1930, mgms.	Total chlorophyll per plant, mgms.	Area of green leaf blades per plant,* sq. cm.	Total dry matter per plant, gms.	Grain yield per plant, gms.
B19 (Nebr. 659)	Very dark	11.30	407	3,603	253	69.7
B43 (U. S. 228-9-1-2-2)	Dark	9.00	320	3,557	283	52.7
B40 (U. S. 228-6-5)	Dark	8.87	282	3,181	197	61.0
B5 (Conn. 1-6)	Medium	8.00	339	4,243	379	26.7
B30 (U. S. 227-1)	Dark	7.98	270	3,381	159	74.5
B37 (U. S. 228-2-2-2-1)	Medium	7.78	371	4,771	293	77.3
B35 (U. S. 228-1-2)	Light	7.48	319	4,269	330	16.7
B16 (Nebr. 733)	Light	6.34	233	3,680	267	47.3
B9 (Nebr. 10)	Medium	6.27	176	2,807	148	33.0
B41 (U. S. 228-7-6)	Medium	5.55	168	3,031	290	24.3
B34 (U. S. 227-6)	Light	5.39	181	3,356	226	30.0
B10 (Nebr. 12)	Medium	5.14	106	2,058	148	35.7

*Green leaf area measured when kernels were in the dough stage of development.

Notable variations in leaf area also occurred between strains, producing differences in total chlorophyll ranging from 106 to 407 mgms. per plant. The total dry matter in tops varied from 148 to 379 grams and the shelled grain from 16.7 to 77.3 grams to the plant.

The 12 inbred strains present a fairly continuous series from the standpoint of chlorophyll concentration and a reasonably satis-

factory series of total chlorophyll values. Although the number of strains is too small to compensate for other genetic differences in individual strains, the lines were chosen without regard for these other characters and may be said to represent a random sample of such characters. The principal limitation is that only such strains as are reasonably easy to propagate were included.

The group of 18 hybrids involving the 12 inbreds as parents, included in Table 5, revealed the same range and distribution of values for chlorophyll concentration as the group of selfed strains. Certain of the hybrids indicated complete dominance of the darker parent (B10 x B19, B41 x B5, B5 x B10), others showed dominance of the lighter parent (B37 x B19, B30 x B19), and many represented some intermediate value. A few (B34 x B10, B40 x B5) were significantly higher in chlorophyll concentration than either parent. As a group, the hybrids exhibited higher concentrations of chlorophyll per unit of leaf area than the means of their respective parents. Differences in leaf area of the various hybrids were not so marked and the total chlorophyll showed a smaller range than chlorophyll concentration, although the richest hybrid contained nearly twice the amount of chlorophyll as the poorest one.

TABLE 5.—*Chlorophyll content of leaves, leaf area, and yield of 18 first generation hybrids of corn, season of 1930.*

First generation hybrids	Chlorophyll concentration per 100 sq. cm. of leaf blade, mgms.	Total chlorophyll per plant, mgms.	Area of green leaf blades per plant*, sq. cm.	Total dry matter per plant at maturity, gms.	Grain yield per plant, gms.
B10 x B19	11.61	607	5,230	368	164
B43 x B19	10.39	607	5,838	453	185
B40 x B5	9.98	499	5,005	427	186
B41 x B5	9.53	556	5,831	435	198
B41 x B19	9.22	533	5,785	430	174
B40 x B43	9.03	469	5,193	419	121
B9 x B16	8.86	481	5,426	386	179
B30 x B19	8.62	434	5,035	408	180
B37 x B40	8.60	501	5,822	446	163
B16 x B19	8.47	494	5,831	403	162
B5 x B10	8.20	426	5,190	463	185
B37 x B19	8.15	420	5,155	420	145
B41 x B40	8.12	415	5,112	391	167
B43 x B35	8.10	417	5,151	396	102
B41 x B37	7.99	374	4,687	419	159
B5 x B16	7.86	483	6,145	427	175
B34 x B10	6.82	332	4,863	338	139
B10 x B35	6.23	345	5,530	348	174

*Green leaf area measured when kernels were in the dough stage of development.

In general, the leaf areas and yields of dry matter and grain of the hybrids were far higher than the mean values of their respective parents, quite contrary to the minor increase in chlorophyll concentration. The larger total leaf areas were almost entirely responsible for the substantially greater total quantities of chlorophyll in the whole plant. From this consideration alone, it is obvious that leaf

area is comparatively independent of chlorophyll concentration, Plant breeders have frequently noted striking differences in area of first and second leaves of F_1 corn seedlings, leaves which are produced before chlorophyll content and synthesis of foods begin to play an important part in the life of the plant. Although chlorophyll concentration influences the effectiveness with which leaves operate after their enlargement, it is obviously independent of the size which the early leaves attain. Chlorophyll content of early leaves must have some effect upon the growth thereafter, and on total yield, because of its relation to synthesis of food. Consequently, chlorophyll concentration might be expected to bear some relation to total dry matter produced and to grain yield, although less pronounced than would be the case were leaf area more definitely controlled by chlorophyll content.

The mean values for chlorophyll and yield of dry matter of the parents involved in producing the various hybrids are given in Table 6. A comparison of the mean chlorophyll concentration values

TABLE 6.—*Mean values for parental strains used in producing first generation hybrids.*

Parents	Mean chlorophyll concentration per 100 sq. cm. of leaf blade, mgms.	Mean total chlorophyll per plant, mgms.	Mean area of green leaf blades per plant, sq. cm.	Mean of total dry matter per plant, gms.	Mean of grain yield per plant, gms.
B10 and B19	8.22	256	2,831	201	52.7
B43 and B19	10.15	364	3,580	268	61.2
B40 and B5	8.44	311	3,712	288	43.9
B41 and B5	6.78	254	3,674	335	25.5
B41 and B19	8.43	288	3,317	272	47.0
B40 and B43	8.94	301	3,369	240	56.9
B9 and B16	6.31	205	3,243	208	40.2
B30 and B19	9.14	338	3,492	206	72.1
B37 and B40	8 33	327	3,976	245	69.2
B16 and B19	8.82	320	3,642	260	58.5
B5 and B10	6.57	222	3,150	264	31.2
B37 and B19	9.54	389	4,187	273	73.5
B41 and B40	7.21	225	3,106	244	42.7
B43 and B35	8.24	320	3,913	306	34.7
B41 and B37	6.67	270	3,902	291	50.8
B5 and B16	7.17	286	3,961	323	37.0
B34 and B10	5.27	143	2,707	187	32.9
B10 and B35	6.31	213	3,164	239	26.2

for the parents with that of the hybrids shows a small general shift upward. The lowest concentration of chlorophyll for the parental means was 5.27 mgms. as compared with 6.23 mgms. for the hybrids, with maximum values of 10.15 and 11.61 mgms., respectively. In contrast with the concentration of chlorophyll, the leaf area, total dry matter, and grain yield of the hybrids ranged from 50 to 100% higher than the mean values of these attributes for the respective parents. Apparently, chlorophyll concentration is controlled by a relatively few genetic factors, while leaf area and yield are the product of a considerably larger number, some of which are cumulative or

complementary in their action. Chlorophyll concentration is important in determining the total chlorophyll per plant at all stages of growth, which in turn doubtless conditions the ability of the plant to synthesize dry matter. The concentration of pigment does not seem to be merely another expression of the hybrid vigor noted in yielding ability, but rather a genetically independent attribute.

The inter-relations between chlorophyll, leaf area, and yield of the group of 12 inbred lines are conveniently expressed in the form of correlation coefficients. In the interpretation of these correlations, allowance should be made for the limited number of strains included, as well as for the unfavorable weather experienced in late summer which hampered normal development of grain. The coefficients shown in Table 7 indicate a comparatively high positive correlation

TABLE 7.—*Correlation coefficients of chlorophyll with plant yield for 12 inbred strains of corn.*

Plant character	Total dry matter per plant at maturity	Shelled grain per plant	Area of green leaf blades per plant	Chlorophyll per 100 sq. cm. of leaf blade
Shelled grain per plant	−.25±.18			
Area of green leaf blades per plant	+.70±.10	+.19±.19		
Chlorophyll per 100 sq. cm. of leaf blade	+.21±.19	+.55±.14	+.38±.17	
Total chlorophyll per plant	+.51±.14	+.46±.15	+.73±.09	+.80±.07

between chlorophyll concentration and total chlorophyll per plant (+.80) and a significant correlation with grain yield (+.55) and with leaf area (+.38). Total chlorophyll was significantly correlated with all other attributes measured, and appeared to be about equally influenced by chlorophyll concentration and leaf area. Shelled grain yield was related to chlorophyll concentration and total chlorophyll, but not to leaf area. Total dry matter not only gave the highest correlation with leaf area (+.70) but was also significantly correlated with total chlorophyll (+.51). The negative correlation of shelled grain and total dry matter in tops (—.25) was doubtless the result of the dry period in July and August during pollination and early kernel development. The moisture shortage placed a premium on limited vegetative development, contrary to the normal condition in this region.

The group of 18 hybrids indicated somewhat different relations between the various attributes than for the inbred lines. However, from the coefficients of correlation in Table 8, total chlorophyll appeared more highly correlated with the other characters measured than any other attribute, similar to the condition noted for the selfed lines. Total chlorophyll was less highly correlated with shelled grain (+.36) than with total dry matter (+.43), possibly because of the abnormally low grain yields obtained. Chlorophyll concentration proved as accurate a measure of grain yield and of total yield as leaf area, but total chlorophyll was an even more satisfactory index. Leaf area was not significantly correlated with chlorophyll concen-

tration. The total chlorophyll per plant was controlled to a greater extent by chlorophyll concentration than by leaf area in this set of hybrids.

Since chlorophyll concentration is an inherited attribute, the positive correlations of chlorophyll with yields of selfed lines and

TABLE 8.—*Correlation coefficients of chlorophyll with plant yield for 18 hybrid strains of corn.*

Plant character	Total dry matter per plant at maturity	Shelled grain per plant	Area of green leaf blades per plant	Chlorophyll per 100 sq. cm. of leaf blade
Shelled grain per plant	+.31±.14			
Area of green leaf blades per plant.	+.32±.14	+.23±.15		
Chlorophyll per 100 sq. cm of leaf blade. .	+.34±.14	+.25±.15	+.13±.16	
Total chlorophyll per plant. .	+.43±.13	+.36±.14	+.59±.10	+.85±.04

also with yields of hybrids, suggest that the pigment content of selfed lines may be an adequate index of the productivity of the hybrids produced from them. Accordingly, the mean values of attributes for the parental strains given in Table 6 were correlated with those of their respective hybrids as recorded in Table 5. The correlation coefficients are shown in Table 9.

TABLE 9.—*Correlation coefficients between average attributes of parental strains and those of the hybrids produced from them.*

Attributes of the hybrids between parental strains	Attributes of the parents used in producing hybrids				
	Total dry matter per plant at maturity	Shelled grain per plant	Area of green leaf blades per plant	Chlorophyll per 100 sq. cm. of leaf blade	Total chlorophyll per plant
Total dry matter per plant at maturity	+.56±.10	+.27±.15	+.54±.11	+.43±.13	+.54±.11
Shelled grain per plant	+.10±.16	—.11±.16	—.09±.16	—.10±.16	—.10±.16
Area of green leaf blades per plant .	+.34±.14	—.03±.16	+.23±.15	+.19±.15	+.28±.15
Chlorophyll per 100 sq. cm. of leaf blade	+.03±.16	+.30±.15	+.02±.16	+.50±.12	+.34±.14
Total chlorophyll per plant . . .	+.17±.15	+.23±.15	+.05±.16	+.50±.12	+.32±.14

These coefficients are unduly affected by the prepotency of certain selfed lines, notably B5 which produced relatively high yields in crosses with all other inbreds, and the lack of prepotency in B19. Since 6 of the 18 hybrids involving these two lines were unusual in behavior, the correlations are based on a population that deviates considerably from a random sample. The major effect is expressed in grain yield, and this condition, in combination with the unfavor-

able weather for grain formation, explains the lack of correlation between grain yields of the hybrids and all attributes of the parents. Other observations, such as those of Nilsson-Leissner (4), indicate that strong positive correlations may be expected between grain yields of inbred parents and their first generation hybrids, under more nearly normal conditions of sampling and weather

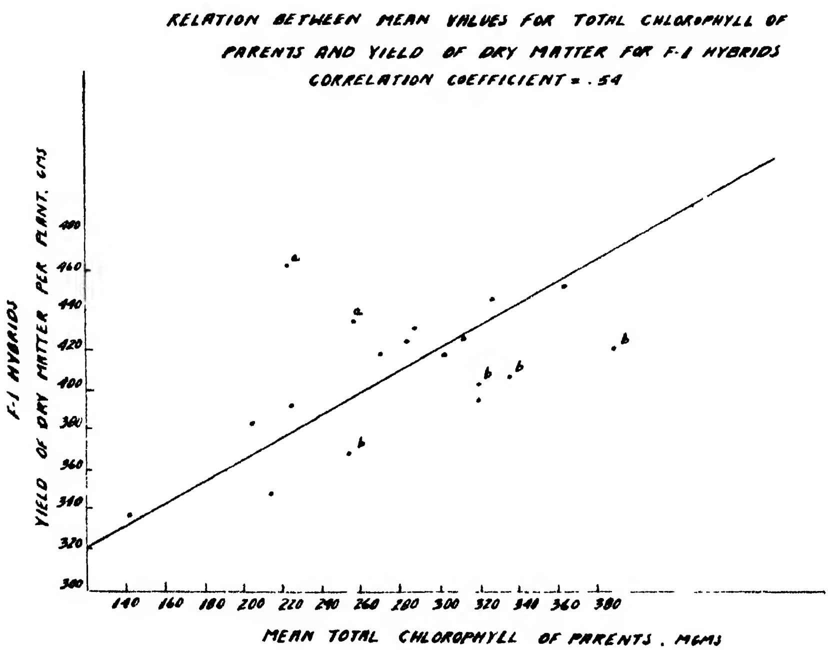

FIG. 2.—The relation of total chlorophyll content of parental inbred lines to yield of dry matter produced by their first generation hybrids. The correlation is more significant than the coefficient of + .54 would suggest, since two of the high-yielding hybrids (a) involved an unusually prepotent line (B5), and four of the low-yielding hybrids (b) involved a line lacking in prepotency (B19).

Turning to the total yield of dry matter in the hybrids, it was found that the mean value for total chlorophyll in the two parents was quite as valuable an index of productivity in hybrids as the mean value of dry matter for the inbreds. Leaf area and chlorophyll concentration of selfed lines were also important indices of productivity in the hybrids. Since leaf area, chlorophyll concentration and total chlorophyll may be determined for selfed lines at the time of pollination or just before without injuring the plant, values of these attributes may serve to indicate which matings of inbreds should be made. Selection within selfed strains toward plants with high chlorophyll concentration and total chlorophyll content would also aid in saving the prepotent lines. (See Fig. 2.)

Leaf area of parents was not significantly correlated with leaf area of their hybrids, nor were chlorophyll concentration and total

chlorophyll of the parents definitely related to leaf area of the hybrids. The chlorophyll concentration of hybrids showed a higher correlation (+.50) with concentration of pigment in the parents than with any other character. In view of the significant correlation between total chlorophyll in the hybrids and the yield of dry matter produced, it is of interest that the total pigment content of the hybrids was more highly correlated with chlorophyll concentration of the parents (+.50) than with any other attribute measured. This furnishes additional support to the view that the greenness of parents is a convenient and reliable index of the productivity of their first generation hybrids. With data at hand on the normal chlorophyll concentration of a given lot of selfed lines, the plant breeder may predict with a fair degree of accuracy which hybrids will be relatively productive, and confine his efforts to such crosses.

In general, light-colored plants in selfed lines should be discarded when selecting parents for the next generation unless they obviously possess some other valuable character. On the basis of these results, light-colored lines may be expected to prove most valuable in producing high-yielding hybrids when mated with strains rich in chlorophyll. Specific information regarding the genetic factors controlling chlorophyll inheritance would still further increase the accuracy with which the results of certain crosses could be predicted.

SUMMARY

1. In a study of methods, it was found that the area of corn leaf blades could be determined as accurately by the formula length x greatest width x 0.75, as by planimeter readings of blue-printed leaf outlines. Leaf areas may conveniently be determined from growing plants by this method without injury.

2. Both chlorophyll and carotin were most concentrated in the uppermost leaves and least in the bottom leaves. The gradient between the uppermost and lowest leaves was fairly regular, and the middle leaf or leaves of the plant exhibited practically the same concentration of pigment as the average for the whole plant. Xanthophyll values were erratic and no significance was attached to such observations.

3. Estimates of total chlorophyll content per plant based on the concentration of the pigment in the middle leaf and on the leaf area determined by the formula were practically as reliable as complete analyses of all leaves. Carotin content of plants was also estimated satisfactorily by this method. A Ganong leaf punch which clips circles 1 sq. cm. in area was used to sample leaf blades without appreciably disturbing the living plant.

4. A group of 12 nearly homozygous selfed lines selected on the basis of observed greenness of leaves in 1929 varied in chlorophyll concentration from 5.14 mgms. of chlorophyll per 100 sq. cm. of leaf for the lightest strain to 11.30 mgms. for the darkest green strain when grown in 1930. Total chlorophyll per plant ranged from 106 to 407 mgms., although no strain showed obvious chlorophyll defects. The 12 strains also differed widely in leaf area, total yield of dry matter, and shelled grain.

5. Eighteen first generation hybrids involving the 12 selfed lines were chosen to represent all combinations of greenness. The chlorophyll concentration within this group ranged from 6.23 to 11.61 mgms., and the total chlorophyll from 332 to 607 mgms. From the chlorophyll content of these hybrids, it appeared that chlorophyll concentration of a given strain may either be genetically recessive, dominant, partly dominant, or cumulative in relation to that of other selfed lines.

6. The mean values of the attributes for the parents of each hybrid suggest that chlorophyll inheritance is controlled by a relatively small number of genetic factors in contrast with leaf area and yield. Chlorophyll concentration in leaves of the hybrids was only slightly greater than the mean value of the parents, whereas leaf areas and yields were 50 to 100% higher.

7. Correlation coefficients between attributes of the 12 selfed lines indicated that total chlorophyll was significantly related to chlorophyll concentration, leaf area, yields of total dry matter, and shelled grain. Chlorophyll concentration was correlated with shelled grain and leaf area, but not with total dry matter.

8. Within the group of 18 hybrids, total chlorophyll was more highly correlated with yields of total dry matter and grain, leaf area, and chlorophyll concentration than any other attribute. Chlorophyll concentration was significantly correlated with production of total dry matter, but not with leaf area.

9. Mean values of the parental attributes of total chlorophyll, chlorophyll concentration, and leaf area were all significantly correlated with total dry weight of the hybrids. Mean chlorophyll concentration of the parents was also closely related to chlorophyll concentration and total chlorophyll of the hybrids.

10. The mean values for chlorophyll concentration and total chlorophyll of selfed lines are reasonably reliable indexes of the total yield that will be produced by their hybrids. Light green inbreds with other desirable attributes should be mated with dark green rather than light green strains for best results Selection of dark green plants in successive generations of segregating strains should be an aid in isolating prepotent lines.

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THE ABSORPTION AND MOVEMENT OF SODIUM CHLORATE WHEN USED AS AN HERBICIDE[1]

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Sodium chlorate is gaining recognition as one of the most effective chemical means now available for the control of perennial weeds and many experiment stations are distributing recommendations for its use. In spite of the proved effectiveness of this chemical as an herbicide, results in the hands of growers are too frequently unsatisfactory. Recommended methods of application may also involve serious fire hazards and the costs have been prohibitive for any but small areas. Greater efficiency in the use of sodium chlorate should follow a better understanding of its action and of the way in which it enters and moves within the plant. The present paper is a contribution toward the solution of the latter problem.

The common practice in the use of chlorate is to apply the material as a spray to the foliage of the growing plant. The greater effectiveness of chlorate when compared with other herbicides which are equally active in killing the exposed portions of the plants has been ascribed to a downward translocation of the herbicide in the stem and roots of the plant. Crafts (3)[3] has shown that a mechanism for such penetration is present in field bindweed (*Convolvulus arvensis* L.) growing in dry soil, in which case, as the soil approaches the permanent wilting point, the cells of the roots develop a considerable water-absorbing power. When the tips of the vines of such plants were cut under eosin solution, the dye was drawn several feet into the roots as the tracheal sap, relieved of tension at the top, was absorbed by the living cells of the root. When herbicides were sprayed upon the foliage, however, the penetration into the xylem was much less effective, and it was only with dry soil and continued moistening of the tops that an appreciable downward movement of toxin could be obtained.

Offord (8) tested the effectiveness of a number of herbicides on *Ribes* sp. and found that materials which reacted rapidly with the protoplasm resulted in a quick killing of exposed portions of the plant, but that the crowns and roots soon sprouted, apparently uninjured. The chlorates, on the other hand, were slow but much

[1]Contribution from the Botany and Plant Pathology Section, Iowa State College, Ames, Iowa. Journal Paper No. B80 of the Iowa Agricultural Experiment Station. Project No. 304. Received for publication January 16, 1933.
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[3]Reference by number is to "Literature Cited," p. 739.

more general in their action and a single application resulted in the complete killing of the less resistant species. He concluded that the slow reaction of the chlorate permitted it to be translocated throughout the plant before the translocating tissues were disorganized. Translocation in living tissues is commonly assumed to occur primarily in the phloem, and Hansen (4) has concluded from the blackened condition of the phloem region in plants killed with chlorate that chlorates are moved in this tissue.

The observations of Aslander (1), Schafer, *et al.* (9), and Loomis, Bissey, and Smith (7) that chlorate may be effectively applied to the soil either while the plants are growing or after the tops are removed by mowing or killed by frost, indicate that other effects than downward translocation within the plant may be involved in the killing of perennial plants by chlorate, and Loomis, Bissey and Smith (7) have suggested that the absorption of chlorate from the soil solution by the roots and rhizomes of perennials may be an important factor in their eradication.

EXPERIMENTAL RESULTS

PENETRATION OF SODIUM CHLORATE INTO THE PLANT

Penetration into the leaves.—Preliminary experiments indicated that a 10% chlorate spray penetrated the upper surface of the leaves of fuchsia (*Fuchsia hybrida* Voss) as readily as the lower, although 90 to 95% of the stomates are on the lower surface, and that wilted tomato leaves were penetrated as readily as turgid leaves. Stomatal penetration appeared to be blocked by the presence of air bubbles within the stomatal cavity.

The leaves of oleander (*Nerium Oleander* L.) were used in more extended experiments on cuticular penetration. This leathery leaf develops an unusually heavy cuticle on its upper surface, and all stomates are located in pits on the lower surfaces Mature leaves of the current season's growth were used, their edges were coated with vaseline to prevent creeping, and a 10% sodium chlorate solution containing a soap spreader was applied with a swab. Three days after the chlorate was applied the leaves treated on the lower, stomatal surface appeared to be slightly more injured than the others, but both lots were dead on the fifth day, indicating effective penetration through the unbroken upper cuticle of these leaves.

When older leaves were used, little chlorate penetrated the very heavy cuticle of the upper surface, but the lower surface on which the cuticle is approximately one-half as thick was penetrated and the leaves killed.

The cuticle of young, chlorated leaves was not changed in appearance nor in resistance to concentrated sulfuric acid, and the indications were that the chlorate had penetrated into the leaf through the solid and uninjured cuticle.

The penetration of chlorates into the roots and rhizomes of plants.—When chlorate sprays of the high concentrations commonly recommended are applied to growing plants, a large portion of the chlorate may reach the soil either directly as spray or by leaching from the sprayed tops. If this portion of the chlorate application is to be

active in the eradication of perennial plants, the salt must be capable of diffusing through and persisting in the soil for some time without losing its toxic properties and it must readily penetrate the underground portions of the plants to be killed.

To test the reaction of herbicides with the soil, 1-liter portions of different prepared sprays were shaken with 200 grams of loam

FIG. 1.- Chlorate injury to leaves of seedling corn Note malformations, striping in veins, and chlorosis and death of tips.

soil. After definite periods of time the mixtures were filtered and the toxicity of each filtrate compared with that of fresh portions of the same material. The toxicity of sodium chlorate was not measurably reduced by 72 hours shaking with soil, while several quick-acting weed killers either reacted with or were adsorbed by the soil and lost their toxicity in 24 hours or less.

Other evidence that sodium chlorate does not lose its toxicity when in contact with soil was obtained by sampling chlorated plats 1 and 2 years after the applications were made and obtaining from these samples chlorate tests with iodides and bromides and typical chlorate striping (Fig. 1) in corn when plants were grown directly in the subsoil or were watered with subsoil leachings. The persistence of chlorate toxicity for 2 full years in Iowa is probably related to the abnormally low rainfall of 1929–31 so that the rate of chlorate decomposition was reduced and leaching was eliminated. The plants shown in Fig. 2 were grown in soil taken 2 years after quack grass (*Agropyron repens* (L.) Beauv.) had been eradicated with sprays containing a total of 1,000 pounds of sodium chlorate an acre.

Untreated subsoil samples gave a growth of corn not distinguishable from the growth in surface samples. The striping and stunting is typical of chlorate injury. These samples gave iodide tests for chlorates and were freed from toxicity by autoclaving. When samples of the soil were leached, the toxic materials were removed from the soil and recovered in the leachings. The evidence seems to justify

FIG. 2. The persistence of chlorates in treated soils. Left to right, plants growing in soil from the first, second, third, and fourth foot levels. Soil samples taken 2 ½ years after an application of 1 000 pounds of sodium chlorate an acre Injury indexes, first foot = 0, second foot = 2.0, third and fourth feet = 4 0

the conclusion that portions of the sodium chlorate remained unchanged in this subsoil for 2 years. After the heavy rains of the winter of 1931-32 these plats were found to be free from chlorates to the 4-foot level.

Two types of experiments have given evidence on the penetration of chlorates into the underground portions of plants, *viz.*, the addition of sodium chlorate to water cultures and the addition of dry or dissolved chlorate to the soil about growing or dormant plants.

Water culture experiments have shown that sodium chlorate is absorbed through the intact roots of corn giving the typical chlorotic striping of the leaves and at higher concentrations or with longer exposures resulting in the death of the plant. Ten p.p.m. of chlorate in the nutrient solution were sufficient to give clear-cut striping within 24 hours, but did not result in the death of the plants within 3 weeks. The slowness of the action of chlorate is illustrated by the fact that plants growing in water cultures containing as much as 1,000 p.p.m. of sodium chlorate sometimes lived for several days, although showing toxic effects within 12 hours or less.

In another series of experiments chlorate solutions were mixed with potting soil to give concentrations of chlorate equivalent to 31, 62, 125, 250, 500, and 1,000 pounds an acre. Corn showed injury at 125 pounds, but soybeans and oats showed chlorate symptoms at the lowest application rates and all plants were killed by the heavier applications. In greenhouse pot experiments a high soil temperature

may result in a relatively rapid destruction of chlorate and the symptoms would then be less severe and persistent than would be expected in the field.

FIG. 3.—The recovery of Canada thistle from applications of sodium chlorate equivalent to 300 pounds an acre. At left, all chlorate applied to top; at right, all chlorate applied to soil.

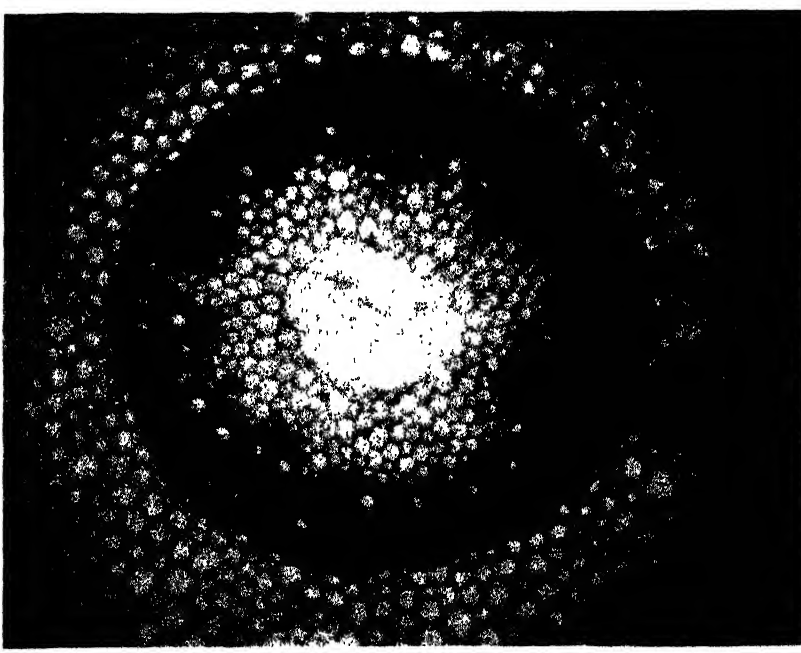

FIG. 4.—Showing early chlorate injury to quack grass rhizome in the xylem, particularly metaxylem, region. Phloem not yet affected.

A large number of pot and field experiments have been performed in which the effectiveness of chlorate when applied to the soil only has been compared with the usual spray applications. All of these experiments indicate that sodium chlorate dissolved in the soil water readily penetrates and kills the roots and rhizomes of either active or dormant plants. The results of one such experiment are illus-

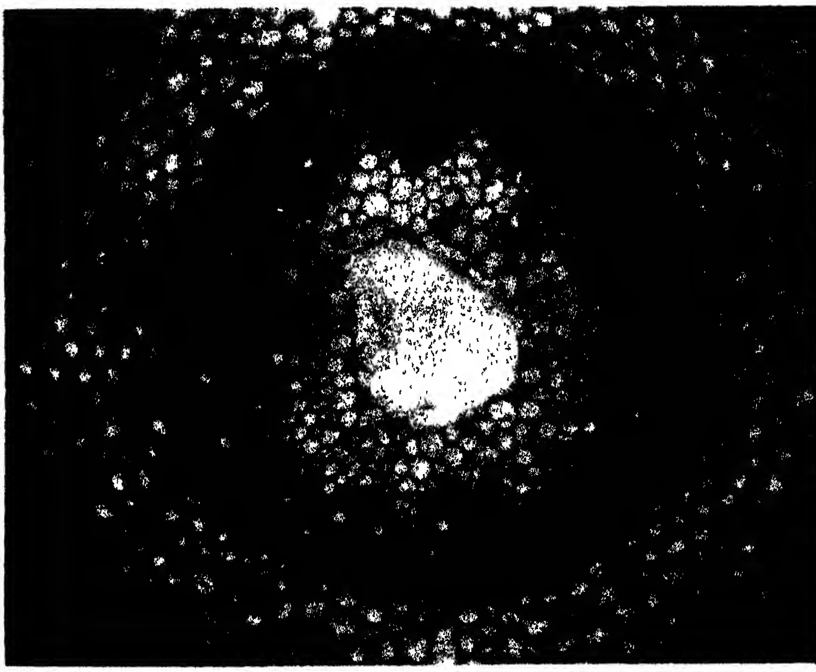

FIG. 5.—A later stage in chlorate injury to quack grass rhizome, showing typical blackening of phloem.

trated in Fig. 3 where the recovery of Canada thistle (*Cirsium arvense* [L.] Scop.) is shown to have been more rapid and complete after a purely foliage application which quickly killed the tops than after the application of an equal quantity of chlorate, equivalent to 300 pounds an acre, to the soil in the pot. With the foliage applications the chlorate killed the stems for about 2 inches below the paraffined surface of the soil and the new growth was normal and healthy. With the soil applications the old plants died slowly, the new growth was weak and chlorotic, and the plants eventually died.

THE TRANSLOCATION OF SODIUM CHLORATE IN PLANTS

The assumption is frequently made that chlorate sprayed on the foliage of perennial plants is translocated downward through the stem to the underground storage organs. Since the normal diffusion of the chlorate would be very slow, this movement has been variously assumed to occur in the phloem or in the xylem. Hansen (4) assigned

the movement to the phloem on the basis of phloem injury in treated plants. Figs. 4 and 5 show that the xylem is the first tissue injured in the quack grass rhizome, the blackening of the phloem occurring at a later stage in the injury. We have also found that chlorates are readily translocated past a ring that cuts through and removes the phloem. Ringed plants of Bryophyllum (*Bryophyllum pinnatum*

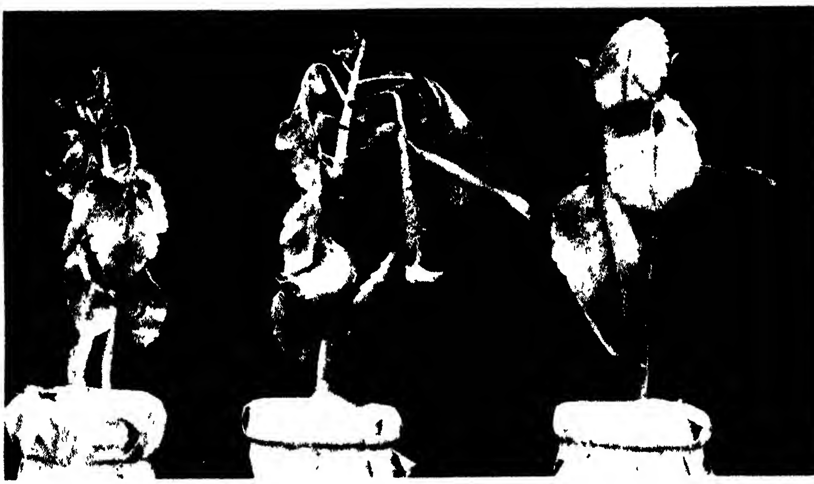

FIG. 6.—Transpiration and the upward movement of chlorate in Bryophyllum. All pots received 1.5 grams sodium chlorate in solution Left to right, normal transpiration, half of leaves covered with vaseline to prevent transpiration, entire top vaselined

Kurz.) were sprayed below a central ring and compared with ringed plants unsprayed and with unringed plants sprayed on the lower leaves. Within 24 hours chlorate injury was apparent at the tips of both the ringed and unringed sprayed plants and after 48 hours the younger leaves of both series were killed, thus indicating upward translocation through the xylem. In other experiments spray applied above a ring was moved through the xylem into the leaves below the ring.

Transpiration and the movement of chlorate.—The importance of transpiration in the upward movement of chlorate is illustrated in Fig. 6. Some of the leaves of Bryophyllum plants were carefully covered with vaseline and sodium chlorate solution was applied to the soil about the plants. The transpiring leaves were killed quickly, but the vaselined leaves showed no chlorate injury after 8 days.

In another experiment the effects of ringing, vaselining, and holding the plants at high humidity upon the rate of transpiration and chlorate movement from the soil were studied. When untreated plants showed a daily transpiration rate of 14 grams, chlorated Bryophyllum plants lost all their leaves in 3 days with many of the leaves killed. When the transpiration rate in the checks was reduced to 2 grams a day by holding the plants in moist chambers, no chlorate injury appeared in the tops of treated plants beyond a slight necrosis

of some of the main veins of the leaves. After 8 days the roots and base of the stem were completely broken down by the chlorate, but no further injury had appeared in the tops. Plants completely covered with vaseline also showed no direct chlorate injury in stem or leaves, but the roots were killed (Fig. 6).

When dormant quack grass rhizomes were drawn through a waterproof partition and sealed in with wax, sodium chlorate applied at the rate of 600 pounds an acre to the soil about one end of the rhizomes killed the exposed portions of the plants, but as long as the untreated ends of the rhizomes were dormant the chlorate injury did not extend more than one-half inch beyond the partition separating the chlorated and untreated soils. As soon as the untreated portions began to grow and transpire, however, enough material was drawn from the dead ends of the rhizomes to produce typical chlorate symptoms in the tops of the untreated side and vascular injury throughout the rhizomes.

The downward movement of chlorate.—If chlorate is translocated in the transpiration stream in the xylem, as the preceding experiments would indicate, the upward translocation of soil applications would be a simple matter, but rapid downward translocation would occur only when transpiring surfaces were attached below the point of entry of the chlorate or when the water deficit of the roots was sufficiently high to produce a backward movement in the stems and roots of plants whose transpiring area had been killed by the spray. The first condition should not be found in a uniformly sprayed field, and the second has been shown by Crafts (3) to be ineffective in the field treatment of deep-rooted plants with sodium arsenite.

The results of an experiment in the downward translocation of chlorate in tomato are illustrated in Fig. 7. The upper third of six tomato plants growing in moist soil and transpiring at an average rate of 160 grams per plant per day and of six plants in dry soil transpiring at a rate of 19 grams a day was sprayed with sodium chlorate. Injury appeared first on the plants growing in moist soil and on the fourth day 84% of the unsprayed leaves on these plants were killed or badly injured while 87% of the lower leaves on the dry plants showed no chlorate injury. The same type of downward translocation was obtained past a ring in the ringed Bryophyllum plants, but in no case was the effect of the chlorate observed below the lowest transpiring leaf. Such movement as this will be important in obtaining a complete top-kill with chlorate sprays and may explain in part the observations of Latshaw and Zahnley (6), Willard (10, 11), and others who have obtained more rapid and complete killing of plants sprayed while the soil was moist. Under these conditions there will also be a more rapid penetration of the chlorate into the soil and it is not possible at present to estimate the relative importance of the two factors.

THE MOVEMENT OF CHLORATE IN THE SOIL

Several plant-indicator and chemical methods of estimating chlorates in the soil were tried and the procedure of using corn as an indicator plant was adopted for general use in the study of the

movement of chlorate in the soil. Corn is rather resistant to chlorate but shows at the same time a well-graduated series of injury symptoms. Four kernels of corn were planted in about 1 kilogram of the soil to be tested and held for 2 weeks at a moderate temperature with careful watering to avoid leaching. The injury shown by the

FIG. 7.—Transpiration and the downward movement of chlorate in tomato. Plants sprayed above points marked with arrows. Plant at left transpiring at rate of 160 grams a day; plant at right in dry soil and transpiring at rate of 19 grams a day when sprayed.

plants was then given a rating or index number according to the scheme in Table 1.

TABLE 1.—*Plant indicator measure of chlorate concentrations.*

Injury shown by corn plants 2 weeks after seeding	Injury index
None	0
Slight stunting, light striping of older leaves	1
Moderate injury, distinct striping	2
Serious injury with heavy striping	3
Plants bleached and dying at two weeks	4
Plants killed without unfolding	5

The most satisfactory chemical method used estimated the chlorate present by its action in oxidizing potassium iodide in a strongly acid solution. The soil to be tested was air dried and ground and 1-kilogram samples were leached with 1,150 ml. of distilled water. About 950 ml. of leachings came through the sample and were made to 1 liter. Twenty-five ml. of this extract were mixed with 25

ml. of 10% KI solution and 35 ml. of concentrated HCl. The mixture was allowed to stand for 20 minutes in a glass-stoppered bottle, diluted with 100 ml. of distilled water, and titrated at once against 1/50 N sodium thiosulfate with starch indicator. Soil extracts from adjoining, untreated plats were used for blank determinations which frequently ran moderately high, especially in the extract from the surface foot. Oxidizing substances present in the treated and not in the untreated soil were calculated as parts of sodium chlorate for one million parts of oven-dry soil.

The large and varying blank determinations obtained with untreated soil led us to choose the plant indicator method in preference to the KI method. The two methods are compared in Table 2. No plant injury was shown by soils that tested less than 10 p.p.m. of chlorate; 1.0 degree of injury was observed with 12 to 16 p.p.m., and 2.0 degrees of injury at 20 to 25 p.p.m. Chemical determinations of chlorate were not made on the more heavily impregnated soils.

TABLE 2.—*A comparison of the plant indicator and potassium iodide methods of determining chlorate residues.**

Depth of sample	Rate of sodium chlorate application					
	1,200 lbs. per acre		600 lbs. per acre		300 lbs. per acre	
	Injury index	$NaClO_3$ in p.p.m.	Injury index	$NaClO_3$ in p.p.m.	Injury index	$NaClO_3$ in p.p.m.
1st foot.	0.0	8.5	0.0	11.2	0	0.6
2d foot..	0.0	2.7	0.0	0.0	0	2.4
3d foot .	0.5	10.9	1.5	12.2	0	2.8
4th foot	2.5	30.9	1.0	16.1	0	4.6

*Chlorate applied Oct. 28, 1930; samples taken May 21, 1932.

The movement of chlorate into the subsoil of heavily sprayed plats and its persistence there is illustrated in Fig. 2. The soil from which these samples were taken received a total of 1,000 pounds of sodium chlorate in the summer of 1929. Soil samples were collected on November 1, 1931, and the photograph taken November 15. The surface foot of soil was clear of chlorate effects and shallow-rooted grasses were growing normally on these plats. The injury in the second foot was classed as 2.0 on the scale described above in which 0 represents no injury and 5 represents the early death of the seedlings. Two and one-half years after the chlorate applications the concentration in the third and fourth feet of this soil gave a 4.0 degree injury to corn. Such persistence is the result of an excessive chlorate application and a subnormal precipitation, but it supplies a possible explanation of the effectiveness of sodium chlorate in controlling deep-rooted perennial plants as well as the dangers of the excessive use of this chemical.

A number of experiments on the control of quack grass with soil treatments have given evidence on the question of the movement of chlorate in the soil. In the summer of 1930, a single application of 300 pounds of chlorate an acre applied in solution after cutting and

removing the tops of a heavy growth of quack grass gave better than a 99% kill. The soil was moist at the time the chlorate was applied, but no rain of more than one-half-inch occurred in the next 2 months. In the dry fall of 1930, soil applications of 150 pounds of chlorate an acre gave a 99+% kill, but an application of 600 pounds of chlorate in the spring of 1931 which was followed within 48 hours by 1.5 inches of rainfall gave no control. Chlorate tests with growing corn plants showed that the subsoil of this plat was heavily impregnated with chlorate, but that the surface foot in which the quack grass was growing had been leached free of toxic quantities of the chemical. With a deeper rooted plant the failure of the treatment might not have been so complete, but its effectiveness could well have been reduced by such movement.

A field study of the movement of sodium chlorate.—In the fall of 1930 three series of plats were laid out and sodium chlorate applications made at rates of 300, 600, and 1,200 pounds an acre in the fall of 1930 and in the spring and summer of 1931 Soil samples were collected to a depth of 4 feet and corn plants grown in the different samples as indicators of their chlorate content. Samples were taken with a large auger and a metal tube was used to prevent contamination of the lower samples by surface soil.

With the dry conditions of 1930 no chlorate of the October 28 application had penetrated into the second foot when the last sample was taken on December 9. Under these same climatic conditions a single application of 150 pounds of dry sodium chlorate in November gave a practically complete control of quack grass. The first spring samples were taken on February 21 and showed some penetration into the second foot with the soil still dry. Total precipitation for the period of February 21 to May 26 was 6.38 inches and on the latter date chlorate was obtained for the first time from the fourth foot sample while the concentration in the surface foot was still highly toxic (Table 3).

TABLE 3.—*The penetration and persistence of fall applications of sodium chlorate.*

Chlorate applied Oct. 28, 1930, lbs. per acre	Depth of sample, feet	Chlorate toxicity index					
		Nov. 20, 1930	Apr. 11, 1931	May 14, 1931	May 28, 1931	July 7, 1931	Nov. 1, 1931
300	0–1	4	4	4	2	4	0
	1–2	0	-	3	4	4	1
	2–3	0	1	2	4	3	2
	3–4	-	0	0	4	1	2
600	0–1	4	4	3	4	5	1
	1–2	0	2	4	4	3	3
	2–3	0	2	4	4	3	4
	3–4	—	—	0	4	3	4
1,200	0–1	4	4	4	4	4	1
	1–2	0	3	4	4	4	3
	2–3	0	0	2	4	4	4
	3–4	—	0	0	4	1	4

Chlorate applications made on April 23, 1931, were followed by good showers and had penetrated into the fourth foot by May 26 at the same time as the fall applications, although in slightly lower concentrations (Table 4).

TABLE 4.—*The penetration and persistence of spring and summer applications of chlorates.*

Chlorate applied April 23, 1931, lbs. per acre	Depth of sample, feet	Chlorate toxicity index				
		May 7, 1931	May 26, 1931	July 7, 1931	Nov. 1, 1931	June 15 application, Nov. 1, reading
300 .	0-1	3	4	4	1	0
	1-2	1	3	4	1	0
	2-3	0	3	3	3	0
	3-4	0	3	1	2	1
600	0-1	3	4	4	0	4
	1-2	0	2	4	0	4
	2-3	0	2	4	1	3
	3-4	0	3	1	1	2
1,200	0-1	4	4	5	2	3
	1-2	0	3	4	2	3
	3-4	0	2	1	3	3
	2-3	0	3	4	3	3

Chlorate applications made June 15 had reached the 3-foot level with index values of 4.0 on July 7 with 1.61 inches of rainfall. September and October rainfall were both above normal and by November 1 there was a clearing of the surface soil in the earlier and lighter applications. Samples taken in May 1932 (Table 2) from the October 1930 plats showed toxic quantities (index 2.5) of chlorate persisting in the fourth foot of the plat which received 1,200 pounds of chlorate, slight injury from the subsoil samples of the 600-pound plat, and no injury from the 300-pound plat.

These experiments would seem to show that sodium chlorate may penetrate deeply into the soil at a rate dependent mainly upon the soil moisture and rainfall, and that heavy applications of chlorate may persist in the subsoil for a year or more.

DISAPPEARANCE OF SODIUM CHLORATE FROM THE SOIL

The inertness of sodium chlorate which permits it to penetrate deeply into the soil and presumably to act on perennial plants over an extended period may have its disadvantage in chlorate injury to succeeding crops planted on treated land. While we have not fully established the fact that this chlorate is not chemically changed, as claimed by Harper (5), its solubility, its stability, and its effect upon the plant and upon iodine compounds may certainly remain unchanged over a period of 2 years. This persistence of the chlorate toxicity has resulted in a chlorosis of plants, particularly of deep-rooted plants, growing on the treated soil. We have found that if

the soil about such chlorotic plants is thoroughly leached or if the plants are transferred to fresh soil before they are too greatly weakened, they recover and grow normally, thus indicating that the chlorosis is the result of the continued absorption of chlorate at low concentrations. After the treated weeds are killed the persistence of chlorate becomes obviously undesirable and an understanding of the ways in which chlorate is removed from or decomposed in the soil is essential to a rational use of the compound.

The removal of chlorate by leaching.—The experiments on movement in the soil reported above are sufficient proof that the chlorate compounds remain soluble and suggest that they should be subject to leaching. Several times in practice a heavy rain shortly after a chlorate application has greatly reduced its effect on the shallow-rooted quack grass, and the observations on chlorate in the soil indicated that the downward movement of the compound was dependent upon the precipitation. Preliminary experiments with leaching indicated that heavy or long-continued leaching of chlorated soil would remove the toxic substances and permit normal growth of plants.

To test the effect of leaching on the removal of chlorate, 1.5 grams of sodium chlorate in solution were thoroughly mixed with 3-kg. samples of potting soil which were then leached with 2,500 ml. of water and the leachings from each pot concentrated under reduced pressure to 30 ml., which should have given, with complete leaching and no decomposition of the chlorate, a 5% sodium chlorate solution. When added to water or soil cultures of corn, this concentrate gave typical chlorate striping. When sprayed on bean leaves, its effect was approximately equal to that of a fresh 2% sodium chlorate solution. Concentrated extract from untreated soil had no effect on either corn or beans. Plant tests on the leached soil indicated that 90 to 95% of the chlorate had been removed.

A second series of pots was set up in the same way and leached with 1, 3, and 8 liters of water and planted to corn. The 1.5-gram application was calculated as approximately equivalent to 1,200 pounds an acre on the basis of oven dry soil. Leaching with 1 volume of water removed most of the chlorate from this soil. The data are presented in Table 5.

TABLE 5.—*The removal of sodium chlorate by leaching.*

Grams of chlorate for 3 kg. of moist soil	Liters of water used for leaching	Index of injury to corn
1.5 (1,200 lbs. per acre)	None	4
1.5	1	3
1.5	3	1
1.5	8	0
0.5 (400 lbs. per acre)	None	1.5
0.1 (80 lbs. per acre)	None	1.0
None	None	0

In a third series three sets of jars were filled, one was held for 30 days at an average temperature of 3°C, another at 18.5°C, and the chlorate was added to the third at the end of the 30-day storage

period when the stored pots were leached as indicated (Table 6) and all were planted together. Leaching was slower in those pots in which the chlorate had stood for 30 days, particularly when held at low temperatures, but there was an appreciable reduction of toxicity in the leached soils.

TABLE 6.—*The effect of standing in the soil upon the leaching of sodium chlorate.*

Grams of chlorate in 3 kg. of moist soil	Liters H_2O used for leaching	Injury index		
		Pots stored at 3°C	Pots stored at 18.5°C	Pots not stored
1.5	None	3	3	3.5
1.5	1	3.5	3	–
1.5	3	1.5	2	–
1.5	8	2	0	–
0.5	None	1	1	1.5
0.1	None	0	0	0

The decomposition of sodium chlorate in the soil.—Sodium chlorate is readily decomposed into sodium chloride and oxygen and its toxicity has been attributed to its decomposition within the plant with the liberation of oxygen at a high reaction potential which disturbs the normal equilibria of the cell. The same decomposition apparently occurs in the soil and is a major factor in the disappearance of chlorates from treated soils.

Greenhouse experience with steam-sterilized soils had indicated that high temperatures hastened the decomposition of chlorate. To test the method, surface soil was collected from a plat which had received 1,200 pounds of sodium chlorate an acre 3 weeks previously. Samples of this soil were autoclaved at 20 pounds pressure for ½, 2, 4, and 8 hours and planted to corn. The growth of the plants is shown in Fig. 8. The toxic index of the soil was reduced from 5.0 for the untreated soil to 3.0 in 2 hours and to 0 in 4 hours.

In a second experiment soil with a toxic index of 4.0 was used to determine the effect of ordinary temperatures on the rate of chlorate decomposition. A part of the soil was air dried in a cool place so that two moisture contents of 14.0 and 23.8% were available to show the effect of moisture as well as of temperature on the reaction. The 23.8% represented approximately the field coefficient or moisture equivalent of this soil. One hundred and sixty paraffined paper cups were filled with about 400 grams of soil each and capped. Twenty containers of soil at each moisture content were stored at each of four temperatures as follows: In a refrigerator at 8°C, in a head house where the temperature varied from 14°C in the early part of the experiment to a high of 33°C toward the middle, and in incubators at 30° and at 40°C. Moisture was added every other day to maintain the original weight and duplicate cups from each treatment were planted to corn each week for 10 weeks. The data are presented in Table 7 and show clearly the retarding effect of low temperatures and low moisture on the decomposition of sodium chlorate in the soil. At 40°C and 24% moisture the toxicity had dropped to 0 in 6 weeks.

At room temperatures it had reached the same point in 10 weeks and at 8°C there was no measurable loss of toxicity in 10 weeks. The retarding effect of low moisture was most marked at the higher

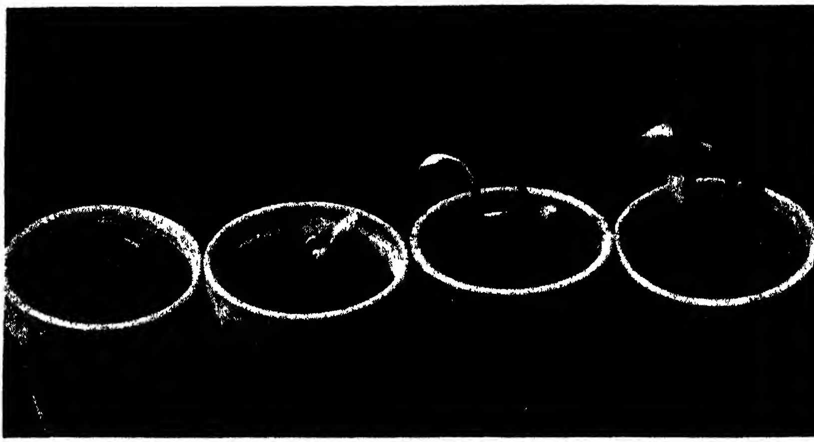

FIG. 8.—The destruction of chlorate in the soil by high temperatures. Left to right, check, autoclaved at 20 pounds for 30 minutes, autoclaved for 2 hours, autoclaved for 4 hours.

temperatures Soil conditions of low moisture and temperature such as would exist in the subsoil of relatively dry, cool regions might be expected to result in the continuance of the residual action of chlorate over objectionally long periods.

TABLE 7.—*The influence of temperature and moisture on the decomposition of sodium chlorate in soil.*

Storage conditions		Injury index after the indicated weeks in storage									
Temperature °C	H_2O %	1	2	3	4	5	6	7	8	9	10
8°	14.0	4	4	4	4	4	4	4	4	4	4
14–33°	14.0	4	4	4	4	4	4	3	4	4	1
30°	14.0	4	4	4	3	4	3	2	2	1	1
40°	14.0	4	4	4	4	3	2	3	2	1	1
8°	23.8	4	4	4	4	4	4	4	4	4	4
14–33°	23.8	4	4	4	3	3	3	3	2	1	0
30°	23.8	4	4	3	4	3	1	1	0	0	0
40°	23.8	4	4	4	3	3	0	0	0	0	0

SUMMARY

1. Sodium chlorate apparently penetrates readily all of the external surfaces of the plant with the exception of unusually heavy cuticle or corky layers and may be expected to gain entrance to the plant whether applied to the leaves, to herbaceous stems, to rhizomes, or to roots.

2. The data presented indicate that the movement of sodium chlorate within the plant is principally in the xylem and is most rapid in the direction of the transpiration stream. With the higher transpiration rate of plants growing in moist soil and moderately dry atmosphere, there was a more rapid spread of chlorate throughout the plant, whether it was applied to a portion of the top or to the soil about the roots. Removing the phloem did not appreciably hinder the movement of sodium chlorate, but checking transpiration by vaselining the leaves or holding the plants in humid atmosphere sharply reduced the movement.

3. Sodium chlorate, whether applied to the soil directly or reaching it in the drip and leachings from sprayed plants, has persisted in the soil in an apparently unchanged form for 2½ years. This chlorate was washed into the subsoil by rainfall and, perhaps because of the lower temperatures, it was particularly persistent when large quantities of the salt were allowed to accumulate in an unleached subsoil. Sodium chlorate in the soil solution may be absorbed by the roots and rhizomes of plants and translocated to the tops so that both tops and roots are killed by the toxin. The efficacy of this herbicide seems to be related to this continued action which may finally result in the death of persistent perennials.

4. The removal of sodium chlorate from the soil by leaching is possible, but large volumes of water are required and the evidence points to the decomposition of the salt as the principal cause of its disappearance. Decomposition is fairly rapid in moist soil at temperatures above 20°C, but may be very slow in cool dry soil. This behavior of the chlorate can be used to advantage both in assuring a continued action on persistent weeds and in avoiding excessive accumulation of chlorates in soils in which decomposition is normally slow.

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THE CALCULATION OF CERTAIN FIBER LENGTH CONSTANTS IN COTTON[1]

O. A. POPE[2]

Investigators working with quality in cotton have long felt the need for a reliable measure of fiber length. Experience has indicated that staple length does not provide a critical measure for the comparison of small differences such as are encountered by cotton breeders because, at best, it is an empirical determination which depends on the estimate of the classer; and in addition to being only a rough estimate of modal length, it gives no indication of the fiber length distribution within the sample.

Within recent years several machines have been designed which enable the operator to separate the different length fractions from a sample of cotton, and it appears that a method for calculating the length from the sorted fractions will enable the investigator to obtain a more accurate and dependable estimate of fiber length than has previously been possible. At present, sorters of the Baer type appear to offer the greatest advantages in fractioning samples of cotton. Fiber research workers are familiar with the technic of fractioning samples, and a comprehensive discussion of the methods would be extraneous to the purpose of the present paper.

Briefly, the process of fractioning is as follows: A prepared sample of about 75 milligrams is placed in a bank of fine combs. The projecting end of the sample is then caught in a pair of special tweezers and a portion of the original sample is removed and transferred to a second comb bank. This process is continued until the entire sample has been transferred. This transfer results in the evening up of one end of the sample and a paralleling of the fibers. A reversal of the second comb bank permits the operator to begin work on the uneven end of the sample and in this way successive fractions are withdrawn in an order of decreasing length. After two or more parallelings the fractions are deposited on a velvet covered board where the length of each fraction is measured. After the length has been determined, each fraction is weighed individually.

GRAPHIC PRESENTATION

Numerous graphic methods have been used to represent the length distribution of a sorted sample. The block histogram with length of fiber plotted as the abscissa and percentage by weight as the ordinate or a polygon drawn through the upper mid points of the successive rectangles serve to give a graphic idea of the character of the distribution and may serve to show marked differences between samples. Such graphs have a tendency to be ragged in the region

[1]Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Published with the approval of the Director as Research Paper No. 309, Journal Series, University of Arkansas. Received for publication January 18, 1933.

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of shorter lengths unless class intervals of ⅛ inch or greater are used. However, a visual comparison of the amount and region of length differences between samples appears to be more difficult when the conventional frequency curve is used than when a cumulative ogive is used (Figs. 2, 3, 4, and 5). A cumulative ogive, when constructed on a percentage basis, is disturbed to only a very slight extent by a variation of the length interval used in measurement. This is an advantage since it allows the use of a small class interval for accuracy in measurement, and does not necessitate the compositing of small classes into larger ones before constructing the graphs.

Information of critical value in regard to the length composition of a sample can be obtained by converting the actual fraction weights to an estimated number of fibers basis. The relative number of fibers for each length fraction is represented by $\frac{W}{L}$, and the percentage number of the total sample which each length fraction contains is represented by the formula: Percentage estimated number of fibers $= \dfrac{100\,\frac{W}{L}}{\Sigma\,\frac{W}{L}}$, where W = weight of the fraction in milligrams, and L is the length of the fraction in the unit of measurement being used.

Comparative frequency distributions on a percentage weight basis and on a percentage estimated number basis are given for the same strain in Table 1. An examination of the frequency distribution on a percentage weight basis shows a distinct uni-modality with a somewhat extended distribution in the direction of the shorter length fractions. In contrast, an examination of the frequency distribution on a percentage estimated number basis shows the presence of a well-defined bi-modality, the second modal group being in the region of lengths less than $\frac{5}{16}$ inch. This second modal group represents a comparatively dense and well-defined substaple of short fibers on the seed. The fact that a short substaple is present on the seed can be definitely determined by carefully detaching the fibers from the seed by hand and sorting. Fiber breakage either in ginning or sorting would serve to increase the amount of fiber in the short fractions. A slight amount of such breakage is probably always present in a mechanically sorted sample, but the comparison of hand-pulled fibers with those removed by a properly adjusted roller gin shows that the breakage of long fibers makes but a small contribution to the amount of short fibers present.

MEASURES OF SAMPLE LENGTH

Modal length has been used in some cases for comparing the length of various samples, but certain serious limitations in the use of this constant are evident. Within uniform samples where the classes in the modal region are closely similar in weight, a variation of a fraction of a per cent is, in some cases, sufficient to cause a pronounced shift in the modal value. Another limitation in the value of modal length

lies in the fact that it is not modified by the length distribution of the entire sample. This latter limitation is a major objection to both staple length and modal length from the standpoint of the cotton breeder, for the spinning utility of cotton is determined, so far as length is concerned, by the entire distribution of its component fibers. Consequently, some method is needed for evaluating length in which all of the length fractions or at least those composing the portion of the total sample used in manufacturing, enter into the calculations.

TABLE 1.—*Comparative frequency distributions on a percentage weight basis and on a percentage estimated number basis for the same strain.*

Length 1/16 in. (L)	Weight in mgms. (W)	Weight distribution, %	Estimated number W/L	Estimated number %
20	0.6	0.39	0.0300	0.18
19	1.8	1.17	0.0947	0.57
18	4.1	2.67	0.2278	1.38
17	7.5	4.88	0.4412	2.68
16	21.5	13.98	1.3437	8.16
15	21.6	14.04	1.4400	8.74
14	20.7	13.46	1.4786	8.97
13	14.8	9.62	1.1385	6.91
12	14.2	9.23	1.1833	7.18
11	8.6	5.59	0.7818	4.75
10	7.2	4.68	0.7200	4.37
9	4.6	2.99	0.5111	3.10
8	5.4	3.51	0.6750	4.10
7	3.6	2.34	0.5143	3.12
6	3.8	2.47	0.6333	3.84
5	2.6	1.69	0.5200	3.16
4	3.7	2.41	0.9250	5.61
3	3.2	2.08	1.0667	6.47
2	3.1	2.02	1.5500	9.41
1	1.2	0.78	1.2000	7.28

	Total sample	Part of sample longer than ½ inch
Σ W	153.8	127.2
Σ W/L	16.4750	9.3907
Σ WL......	1912.10	1776.10
M±P.E./16 in.	9.335±.8936	13.545±.5238

Per cent ½ inch and less = 17.3

MEAN FIBER LENGTH

In view of the failure of staple length and modal length to give a dependable estimate of the fiber length within a sample of cotton and the difficulties encountered in interpreting graphic presentation of sorted samples, it is believed that a calculation of the mean length will furnish a statistic which is both more consistent and efficient than length measures previously used.

The conventional formula for calculating the mean and probable error of the mean is not applicable to the distribution obtained from

fiber sortings because of the peculiar form of the raw data. However, the following adaptation of the conventional formula

$$\text{Mean} \pm \text{P.E.m.} = \frac{\Sigma W}{\Sigma \frac{W}{L}} \pm .6745 \frac{\sqrt{\Sigma WL - (\Sigma W)\ M}}{\Sigma \frac{W}{L}},$$

where W = weight of the fraction in milligrams and L = length of the fraction in the unit of measurement being employed, appears to provide a satisfactory method of expressing the length of a sorted sample. It is obvious that the above modification is necessary in view of the fact that the actual weight of each fraction is the product of the number of fibers contained in the fraction, times the length of each fiber.

In Table 1 the method of calculating the mean length according to the formula previously presented in this paper is illustrated. Mimeographed data sheets are used in the laboratory for recording the original weights of the sorted sample, and the calculated constants are entered on this sheet in a form similar to Table 1. In this table the calculation of mean length and the probable error of the mean length is carried out for the entire sample and for the portion of the sample over ½ inch in length. Since there is considerable variation between samples with regard to the distribution within the shorter lengths, it becomes necessary to draw an empirical dividing line between long and short portions in order to make comparisons between samples. If this division is made between 8/16 and 9/16 inch, it is found that the percentage by weight of the total sample which is ½ inch and less in length varies ordinarily between 10 and 25. In contrast to this we find that the percentage estimated number of fibers within the same length portion of the sample ranges usually between 50 and 70% for the same series of strains.

Certain facts in regard to the composition and utilization of cotton indicate that the mean length for that part of the sample over ½ inch in length will be of greater value in comparing strains than the mean length of the total sample First is the fact that a second modal tendency occasioned by a short substaple has a pronounced effect in lowering the mean length, as is illustrated by the difference between 13.545 and 9.335 (Table 1). Second, it is reasonably certain that spinning waste is composed largely of short fibers, and therefore, if the total sample is included in the calculation of mean length the result will be seriously affected by a portion of the sample which does not enter into the manufactured product. Third, it is desirable to have a measure of the fiber length of that portion of the total which is utilized in manufacturing. Fourth, it is more difficult technically to separate accurately the shorter length fractions and slight errors in sorting the short fractions will have an influence upon the mean length of the total which is out of proportion to either their actual weight or their manufacturing importance. Considering the foregoing facts, it appears feasible to report the results of a length analysis on a dual basis of mean length of the longer portion of the sample and percent by weight of fibers in the shorter portion of the sample. In this way, when the mean lengths are comparable and the

percentage of short fibers differ, or when the percentage short fibers are comparable and the mean lengths differ, there is available a basis for correlations with spinning behavior, and when such correlations have been established a method will be available for predicting the probable manufacturing value of new strains as far as length is concerned.

In an attempt to isolate the specific influence of the fractions ½ inch and less on the calculated values for the mean of the entire sample, coefficients of correlation were calculated between the mean length for the entire sample and the per cent by number of fibers ½ inch and less in length in five replicated sortings made from each of four different varieties. The correlation coefficients found for these four varieties were —.9712, —.9660, —.9388, and —.9648, all of which exceed a significant value of P, according to Fisher.[3] These significant values serve to identify the influence of the shorter fractions on the mean length of the total sample, and since most of the shorter fibers will be eliminated in the process of spinning it appears logical that their influence on mean length should be prevented from entering into the calculation of a constant which is devised for the purpose of comparing length differences between the usuable portion of fiber from different samples. Coefficients of correlation were also calculated between the mean length over ½ inch and the percent by number of fibers ½ inch and less in length for the same replicated sortings. The values found for r were — 4393, +.2742, —.4618, and +.4861, none of which are significant. The lack of agreement in sign and the lack of significant values for these correlations indicate that the mean length calculated for the portion of the sample over ½ inch in length is free from the influence of the shorter fractions, and therefore a more reliable measure of the length of usable fiber than the mean of the entire sample. Obviously this formula can be efficient only when fiber weight per unit length is reasonably constant throughout the sample.

Due to the limited amount of work previously done in determining the linear relationship between fiber weight and length, it was deemed advisable to conduct further tests for the purpose of studying the influence of departures from linearity on the mean length.

Three strains were chosen for this study, *viz.*, A-2 representing the Express group and suitable for delta lands, H-2 representing the Rowden group, and E-2 the Acala group, the two latter being medium length strains adapted primarily to upland soils but also grown to a considerable extent in delta regions.

A representative sample of fiber from each strain was sorted by the Baer method, each length fraction being placed on a velvet-covered board and carefully measured. The fractions varying in steps of ⅛ inch from 4/16 inch to the maximum fraction containing sufficient fibers for a reliable average were then designated for this study. The counting of fibers within each length fraction was done by withdrawing a thin sample of paralleled fibers, placing it between a glass slide and cover-glass, and counting the number of fibers with a microscope.

[3]FISHER, R. A. Statistical Methods for Research Workers. 1930.

Counting on each fraction was continued until 500 or more individual fibers had been isolated, except in a few cases where less than that number were available when all were counted.

The counted samples for the different length fractions were conditioned under constant temperature and humidity before weighing. Each fraction was then accurately weighed, and the calculations to

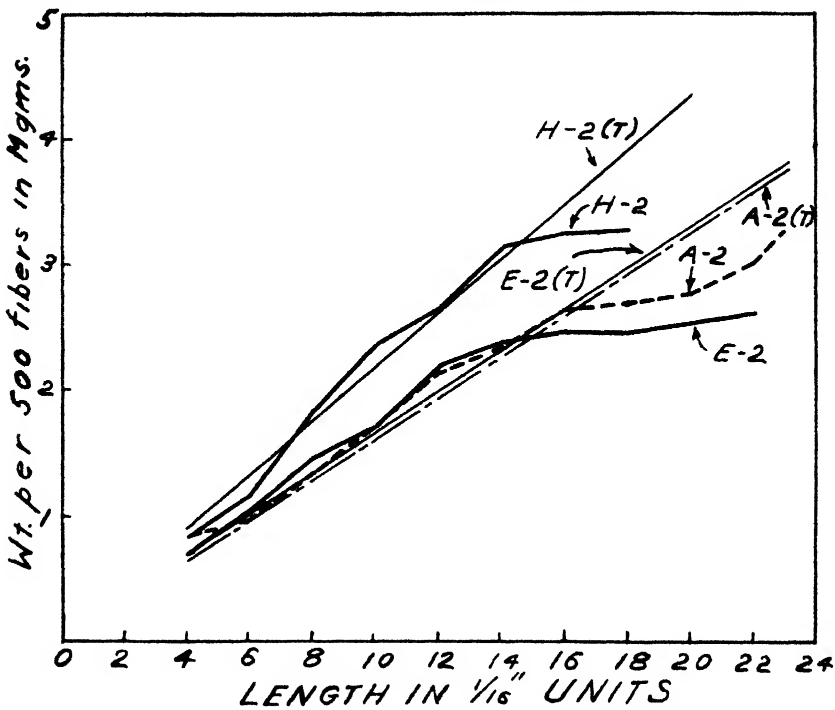

FIG. 1.—Curves showing the fit of actual to theoretical weight per unit length for three strains.

determine the effect of the departures from linearity on the calculated mean length over ½ inch were carried out (Tables 2, 3, and 4). For the purpose of the present study we are concerned primarily with the departures from linearity in that portion of the sample over ½ inch in length, and consequently calculations are not given for the total sample, although the departures from linearity in these samples are less among the shorter fractions than among the longer ones.

A graphic presentation of the fit of actual to theoretical length-weight relationship is shown for the three strains, Fig. 1. In each of the strains there is a considerable decrease in weight per unit length among the longer fractions, while through the remainder of the lengths there is a reasonably good fit of actual to theoretical. The decreases shown among the longer fractions in weight per unit length become of negligible importance, when the weight per unit length is considered in connection with the percentage distribution of fiber

TABLE 2.—*Weight per unit length for H-2.*

Length $\frac{1}{16}$ inch units (L)	Number of fibers	Weight: Actual, mgms.	Weight: Per 500 fibers. mgms.	Weight: Per 500 inches, mgms.	Weight distributions % (W)	Per cent of mean weight	Deviation from mean	$\frac{W}{L}$	$\frac{W}{L}$ corrected
18	504	3.3	3.27	2.91	4.23	84.074	15.926	0.2350	0.2724
16	507	3.3	3.25	3.25	18.86	93.897	6.103	1.1787	1.2506
14	658	4.1	3.12	3.56	27.50	102.853	—2.853	1.9643	1.9083
12	563	3.0	2.66	3.55	18.85	102.564	—2.564	1.5708	1.5305
10	676	3.2	2.37	3.79	10.27	109.498	—9.498	1.0270	0.9295
8	635	2.3	1.81	3.62	6.50	104.586	—4.586	0.8125	0.7752
6	602	1.4	1.16	3.10	4.81	89.563	10.437	0.8017	0.8854
4	610	1.0	0.82	3.28	4.10	94.763	5.237	1.0250	1.0787
Sum over ½ inch					79.71			5.9758	5.8913

Sum WL over ½ inch 1,091.80
Mean weight per 500 inches = 3.46125 mgms.
Mean length over ½ inch = 13.34 ± .60 ($\frac{1}{16}$ inch)
Mean length over ½ inch, corrected to actual fiber weight = 13.53 ± .42
Mean difference due to correction = .19/16 inch, or approximately 1/84 inch

TABLE 3.—*Weight per unit length of E-2.*

Length $\frac{1}{16}$ inch units (L)	Number of fibers	Weight: Actual, mgms.	Weight: Per 500 fibers, mgms.	Weight: Per 500 inches, mgms.	Weight distributions percent (W)	Per cent of mean weight	Deviation from mean	$\frac{W}{L}$	$\frac{W}{L}$ corrected
21	77	0.4	2.60	1.98	1.32	75.741	24.259	0.0629	0.0782
20	735	3.7	2.52	2.01	1.28	76.888	23.112	0.0640	0.0788
18	631	3.1	2.46	2.18	11.30	83.391	16.609	0.6278	0.7321
16	748	3.7	2.47	2.47	20.82	94.485	5.515	1.3012	1.3730
14	574	2.7	2.35	2.69	26.12	102.900	—2.900	1.8657	1.8116
12	638	2.8	2.19	2.93	14.09	112.081	—12.081	1.1742	1.0323
10	525	1.8	1.71	2.74	7.83	104.813	—4.813	0.7830	0.7453
8	483	1.4	1.45	2.90	5.40	110.933	—10.933	0.6750	0.6012
6	713	1.5	1.05	2.81	3.32	107.491	—7.491	0.5533	0.5119
4	773	1.0	0.65	2 59	3.73	99.075	0.925	0.9325	0.9411
Sum over ½ inch					82.76			5.8788	5.8513

Sum W L over ½ inch = 1202.90
Mean weight per 500 inches = 2.61418 mgms.
Mean length over ½ inch = 14.08 ± .70 ($\frac{1}{16}$ inch)
Mean length over ½ inch, corrected to actual fiber weight = 14.14 ± .66
Mean difference due to correction = .06/16 inch, or approximately 1/267 inch

TABLE 4.—*Weight per unit length of A-2.*

Length $\frac{1}{16}$ inch units (L)	Number of fibers	Weight			Weight distributions percent (W)	Per cent of mean weight	Deviation from mean	$\frac{W}{L}$	$\frac{W}{L}$ corrected
		Actual, mgms.	Per 500 fibers, mgms.	Per 500 inches, mgms.					
23	139	0.9	3.24	2.25	1.21	86.719	13.281	0.0526	0.0596
22	403	2.4	2.98	2.17	2.18	83.635	16.365	0.0991	0.1153
20	636	3.5	2.75	2.20	7.64	84.791	15.209	0.3820	0.4401
18	561	3.0	2.67	2.38	18.45	91.729	8.271	1.0250	1.1098
16	589	3.1	2.63	2.63	16.94	101.364	—1.364	1.0587	1.0443
14	686	3.2	2.33	2.67	19.49	102.906	—2.906	1.3921	1.3516
12	589	2.5	2.12	2.83	10.76	109.073	—9.073	0.8967	0.8153
10	551	1.9	1.72	2.76	6.44	106.375	—6.375	0.6440	0.6029
8	571	1.5	1.31	2.63	5.37	101.364	—1.364	0.6712	0.6620
6	417	0.8	0.96	2.56	4.52	98.666	1.344	0.7533	0.7634
4	483	0.8	0.83	3.31	3.66	127.573	—27.573	0.9150	0.6627
Sum over ½ inch					83.11			5.5502	5.5389

Sum WL over ½ inch = 1298.11
Mean weight per 500 inches = 2.5946
Mean Length over ½ inch = 14.97 ± .89
Mean length over ½ inch, corrected to actual fiber weight = 15.00 ± .87
Mean difference due to correction = .03/16 inch or approximately 1/533 inch

lengths within the sample. The longer length fractions which show a decrease in unit weight constitute only a small part of the entire sample and for this reason the effect of these variations on the mean length over ½ inch is small, as is evident from a comparison of the values when calculated in the ordinary manner with the similar values corrected to the actual weight per unit length (Tables 2, 3, and 4). The differences in mean length of the three samples due to correction are, 0.19/16 inch, 0.06/16 inch, and 0.03/16 inch, which, when converted to simple fractions, gives a maximum correction value of approximately 1/84 inch and a minimum correction of 1/533 inch, all of which are not significant from a practical consideration as well as a statistical one. The changes in the values for the probable error of the mean due to correction are of the same order as those for the mean and likewise not significant

A consideration of all available evidence on the linear relationship between fiber weight and length shows that there has not been found in any case, a departure from a linear relationship of sufficient magnitude to affect significantly the calculation of mean length by the method proposed

After the formula for the calculation of the mean length had been tried out in the laboratory, a careful search of the literature for similar methods revealed that a partially equivalent method had been presented by Johannsen[4] in 1914 under the name of "medium length" His formula gives an equivalent value for mean length of the total sample, but does not provide a method for calculating either the mean length of the usable portion of sample, the probable error of the mean, or the coefficient of variability for the sample. These additional statistics appear to be of major importance in the comparison between samples.

COMPARISON OF MEAN LENGTH WITH OTHER MEASURES OF LENGTH

Twelve strains were selected for the comparison of the accuracy of various length constants.

A tabulation of the calculated constants for the 12 strains is presented in Table 5. The mean length ±P E. was calculated both for the total sample and for that portion of the sample over ½ inch, as well as the coefficient of variability for each of these measures. The percent ½ inch and less on a weight basis and the modal length are also tabulated for each strain. In the first three portions of the table, four strains are arranged under each staple length group in the order in which they occur in the graphs. The first two strains under each staple length group are closely equivalent in actual length of fiber as shown by the length curves. The last three strains under each staple length group represent a series of strains in which the actual lengths differ, arranged in a descending order of length. It will be noticed that in each of the series of three, under each staple length, one of the strains used in the closely equivalent pair is repeated in order to connect properly the relationship of all four strains.

[4]JOHANNSEN, OTTO. Die Herstellung von Stapeldiagrammen. Leipziger Monatsschrift für Textilindustrie, Heft 6/7. 1914.

TABLE 5.—*Calculated constants for varieties shown in graphs.*

Sample	Mean length ± P.E.m.		Per cent ½ inch and less	Coefficient of variation		Modal length $\frac{1}{16}$ inch
	Total sample	Over ½ inch		Total	Over ½ inch	
			Staple Length, 29/32 in.			
H-1	8.38± .71	12.51±.51	25.57	12.56	6.04	13
L-1	8.62± .71	12.41±.48	23.62	12.21	5.73	13
G-1	9.34± .88	13.80±.57	17.76	13.97	6.12	14
M-1	9.38± .86	13.20±.51	16.80	13.59	5.73	15
H-1	8.38± .71	12.51±.51	25.57	12.56	6.04	13
			Staple Length, 30/32 in.			
G-2	10.84± .90	13.91±.51	12.28	12.31	5.44	15
F-2	9.98± .94	13.98±.51	13.34	13.96	5.41	14
G-2	10.84± .90	13.91±.51	12.28	12.31	5.44	15
J-1	9.42± .81	13.44±.53	18.55	12.75	5.85	16
K-2	8.89± .74	12.18±.47	20.81	12.34	5.72	10
			Staple Length, 33/32 in.			
E-2	9.58±1.02	14.37±.61	15.10	15.79	6.29	15
J-2	10.16± .97	14.30±.61	15.57	14.15	6.32	15
C-1	10.39± .96	14.89±.82	20.47	13.70	8.16	17
J-2	10.16± .97	14.30±.61	15.57	14.15	6.32	15
L-2	10.10± .90	13.56±.55	15.36	13.21	6.01	14
			Similar Actual Lengths and Different Staple Lengths			
G-1	9.34± .88	13.80±.57	17.76	13.97	6.12	14
L-2	10.10± .90	13.56±.55	15.36	13.21	6.01	14

In the last division of Table 5 a comparison is made between the calculated constants for two strains which are closely equivalent in actual length but between which the cotton classer made a discrimination of 4/32 inch.

Staple length determinations were made by a commercial cotton classer who was not connected with the Experiment Station but who was employed to do all of the stapling for the variety and strain tests. In this way any possibility for the personal preference of the cotton breeder to influence the staple designation of any particular strain was eliminated, and therefore, it is reasonable to consider such variations as are found to be representative of the inaccuracies which occur when staple length is depended upon as an estimate of length.

Some very significant facts concerning the relative reliability of the different length measures considered are revealed when Figs. 2 to 5 are compared with the calculated constants (Table 5).

Due to necessary economies in space, graphs of the closely equivalent pair of varieties in each of the three staple lengths considered are not presented in this paper. The variation in actual lengths between the closely equivalent pair did not in any case exceed the deviations shown in Fig. 5. This figure, therefore, may serve as a visual sample of the maximum deviation found in the three pairs having closely equivalent calculated mean lengths.

Fig. 2 shows the cumulative ogives of the fiber length distributions, on a percentage weight basis, for three strains of cotton which were given the staple length designation of 29/32 inch by a commercial cotton classer. Strains G-1, M-1, and H-1 have actual length distributions in the decreasing order named. The mean of total sample (Table 5) fails in the case of M-1 to follow the decreasing order of

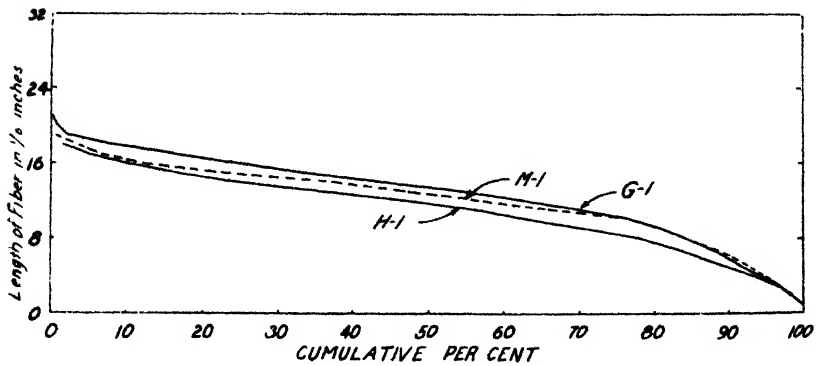

FIG. 2.—Comparative ogives for strains G-1, M-1, and H-1, which differ in actual length. Staple length designation 29/32 inch.

actual lengths, due to limitations previously discussed. The values for mean over ½ inch decrease in order of actual lengths, indicating the reliability of this constant to detect actual differences in their proper proportion. The coefficient of variability values for total sample decrease in order of actual lengths, while for that part of the

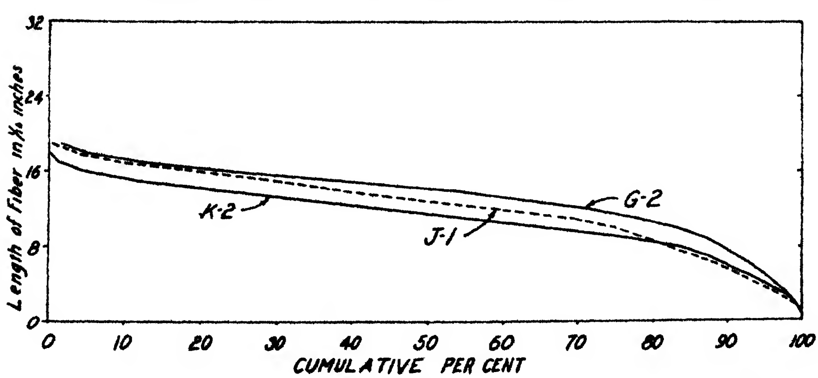

FIG. 3.—Comparative ogives for strains G-2, J-1, and K-2, which differ in actual length. Staple length designation 30/32 inch.

sample over ½ inch an increase for H-1 disturbs the sequence of decreasing values. The increase in H-1 is occasioned by a steeper line of slope in the curve and substantiates the theory that the coefficient of variability is of value as a measure for comparing the length dispersion between different samples.

The length distributions for three strains representing the 30/32 inch staple length group are presented in Fig. 3. The length curves for

strains G-2, J-1, and K-2 show that the strains vary considerably in actual length, although a staple designation of 30/32 inch was given to each. Reference to the calculated constants for these strains shows decreasing values for mean length in the same order and as near as can be told by inspection in the same degree as is shown by the length curves. The per cent ½ inch and less increases in the

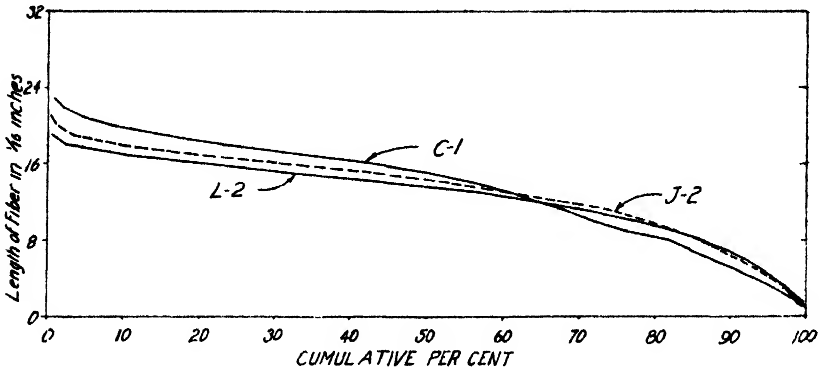

FIG. 4.—Comparative ogives for strains C-1, J-2, and L-2, which differ in actual length. Staple length designation 33/32 inches.

direction of decreasing mean lengths which normally is expected. The coefficient of variability for strain J-1 is larger than for either of the other two, being associated with a more sloping curve.

Fiber length curves for three strains having staple length designations of 33/32 inches are shown in Fig. 4. Strains C-1, J-2, and L-2 vary considerably in actual length. The mean length of total sample for the three strains are closely equivalent, but the mean length for the part over ½ inch decreases in the same order as the actual lengths. The fact that in strain C-1 the coefficient of variability for total sample is less than J-2 is due to the greater total weight of sample C-1, and when calculated on a percentage distribution, C-1 has the greater value. The coefficient of variability over ½ inch is much higher in strain C-1 than for the other two samples, furnishing an example of the efficiency of the coefficient of variability as a measure of length dispersion.

In Fig. 5 are superimposed the length distribution ogives of two strains which are closely equivalent in actual length but to which the cotton classer assigned staple lengths of 29/32 and 33/32 inches, respectively. Reference to Table 5 shows that there is no significant difference in mean length between the strains. However, the very significant fact is brought out in the comparison between these two strains that staple length, on which price is based, fails to coincide with the actual length of the sample. In this case strain L-2 would ordinarily command a premium of 100 points or $5.00 per bale over strain G-1. In cases such as this either the producer of strain G-1 will receive less than a fair price for his cotton or the manufacturer who buys strain L-2 will pay more than the cotton is worth. In either eventuality, the proper cooordination for the best interests

of the cotton industry is lacking. The frequency with which such cases are found in the fiber laboratory indicates that such errors are to be normally expected when staple length is used to estimate the length of cotton. It would be unduly optimistic to expect that the commercial crop as a whole would, in the near future, be handled on any other basis than staple length, but it appears highly desirable

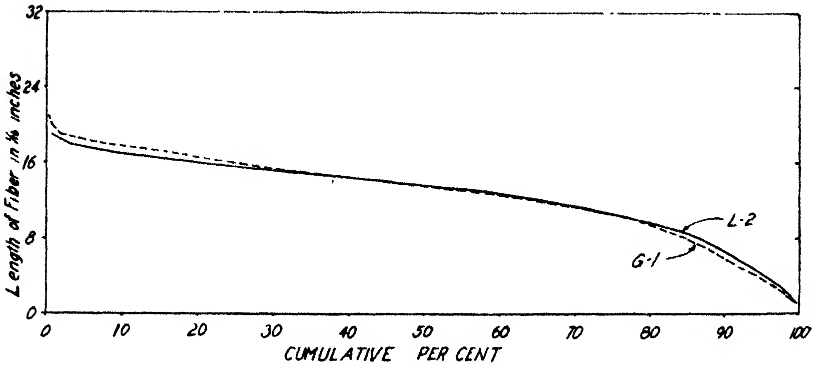

FIG. 5.—Comparative ogives for strains which are closely similar in actual length but which have different staple length designations. Strain L-2 has a staple length of 33/32 inches, and strain G-1 has a staple length of 29/32 inch

that plant breeders and others concerned with the improvement of cotton should use length tests which are more critical and reliable than those used in the past.

TABLE 6.—*Comparison of mean length over ½ inch with modal length and staple length in 12 strains.*

Strain	Mean length over ½ inch, $\frac{1}{16}$ inch	Modal length, $\frac{1}{16}$ inch	Staple length, $\frac{1}{32}$ inch
K-2	12.18	10	30
L-1	12.41	13	29
H-1	12.51	13	29
M-1	13.20	15	29
J-1	13.44	16	30
L-2	13.56	14	33
G-1	13.80	·14	29
G-2	13.91	15	30
F-2	13.98	14	30
J-2	14.30	15	33
E-2	14.37	15	33
C-1	14.89	17	33

The 12 strains were arranged in order of mean length over ½ inch to compare more easily the relationships of this constant with modal length and staple length (Table 6). It appears that there is a tendency for modal length to increase in the direction of increasing mean lengths, but the distribution of modal lengths is too erratic to be of practical value as an accurate estimate of length.

A comparison of mean length over ½ inch with staple length shows that in all cases staple length exceeds mean length with a tendency for staple length to increase with increasing mean lengths. In view of the demonstrated reliability of mean length over ½ inch as a measure of actual fiber length within the usable portion of the sample and the poor agreement of staple length with mean length, this distribution offers evidence that staple length is a definitely inferior measure of actual fiber length.

A comparison of modal length with staple length for the same 12 strains shows that the range of distribution is wide and denotes poor agreement between the two measures. The distribution of values suggests that there is a tendency for staple length to exceed modal length.

A critical analysis of the interrelationships of mean length, modal length, and staple length may be obtained through an interpretation of the correlation coefficients Simple correlations were calculated between each of the pairs and the following values found:

$$r_{\text{mean, mode}} = .7983,\ r_{\text{mean, staple}} = .6732, \text{ and } r_{\text{mode, staple}} = .4063$$

The relationship between mean and mode appears highly significant, the correlation being greater than that required for a P value of .01, according to Fisher[5] This indicates a definite tendency for modal length to increase with increasing mean length, but even though significant, the correlation value is not high enough to justify the use of modal length as an accurate measure of fiber length in the sample

The correlation between mean length and staple length falls between the levels of significance for P values of 0.01 and 0.02 showing a reasonably significant tendency for staple length to follow mean length, but the value of the correlation coefficient indicates that it is even slightly inferior to modal length and greatly inferior to mean length as a measure of the actual fiber length in the usable portion of the sample The failure of the correlations of these two values with mean length to be great enough for accurate predictive purposes logically leads to the expectation that the correlation of modal length with staple length will not be very high, and such is found to be the case, the value of r being less than that required for a P value of .1. This low value indicates a scattered distribution and no definite relationship between modal length and staple length.

SUMMARY

The experience of research workers has indicated that staple length does not constitute a critical estimate of the fiber length in a sample of cotton, and that the modal length of a sorted sample is open to many of the same objections as staple length.

Because of the form of the raw data in a sorted sample, it is not possible to apply the conventional formula for the mean and probable error of the mean. A modification of the conventional formula to fit the unusual stiuation encountered is presented. In applying the modified formula it becomes necessary to convert the weight of each

[5]*Loc. cit.*

fraction to an estimated number basis. Such conversion reveals the fact that a second modal region comes into expression in the shorter part of the sample and exerts a pronounced effect on the mean length calculation. Inasmuch as a large proportion of the shorter fibers are discarded in the manufacturing processes, it appears logical to expect that a mean length calculated from the portion of the sample containing the longer fibers will give a value which will reveal more accurately the actual length differences between samples. The division between the longer and shorter portions of the sample used in the tests reported in the present paper was made between the 8/16 and 9/16 inch fractions. The shorter length portion including lengths ½ inch and less are reported as percentage by weight of the total sample.

The correlation between the percentage number of fibers ½ inch and less in length and the mean for the total sample was determined for five replications in each of four varieties, and values for r of —.9712, —.9660, —.9388, and —.9648 identified the major cause of the variations between mean lengths of replicated sortings from the same sample. Correlations were also calculated between percentage number of fibers ½ inch and less in length and the mean over ½ inch. The values found for r are as follows: —.4393, +.2742, —.4618, and +.4861. The absence of statistically significant values and lack of agreement in sign are evidence that the mean length over ½ inch is free from a direct influence of the shorter fractions. These considerations in connection with the fact that much of the shorter portion of the sample is discarded during the process of manufacturing suggest the validity of calculating the mean length for the longer portion of the sample, and reporting the shorter portion as percentage by weight.

The accuracy of the formula presented is dependent upon a reasonable constancy of weight per unit length in the various length fractions within the sorted sample. An analysis of the weight per unit length for the various fractions in three different samples showed a maximum correction of 1/84 inch and a minimum correction of 1/533 inch, indicating that no significant error may be expected from variations in weight per unit length within the sample.

Comparisons of the calculated constants with actual fiber length curves and with staple length and modal length establish a number of important relationships.

Mean length of total sample was found to have limitations in value due to the influence of short length fractions.

Mean length for the part of the sample over ½ inch in length was found in all cases to be closely equivalent for strains having the same actual lengths. Where the actual length differed, mean length over ½ inch was found in all cases to take values corresponding to the order of actual lengths; and as near as can be told by visual comparison to actual lengths, mean length over ½ inch also corresponded in degree to the actual length differences present.

The demonstrated reliability of mean length over ½ inch to evaluate accurately the direction and proportion of actual differences

present affords a basis for comparing the relative reliability of modal length and staple length as estimates of fiber length.

Modal length was usually found to exceed mean length, but its erratic distribution indicates that it is of little or no value as an accurate estimate of fiber length.

Staple length was found to exceed mean length over ½ inch in all cases. However, its poor agreement with increasing values of mean length shows that it is definitely inferior to the latter measure as an estimate of fiber length, although it appears to be slightly superior to modal length.

A comparison of modal length with staple length reveals the fact that staple length usually exceeds modal length, but there is no other significant relationship between the two measures.

The use of a dual basis, consisting of mean length over ½ inch and percentage by weight of fibers ½ inch and less, offers a point of approach for studies of the relationship of length to spinning performance. By holding one measure constant and varying the second in successive steps it should be possible to establish the relationship between differences of any given magnitude and spinning performance.

THE EFFECT OF FERTILIZERS AND RAINFALL ON THE LENGTH OF COTTON FIBER[1]

E. B. Reynolds and D. T. Killough[2]

The spinning value of cotton fiber is influenced by its length, strength, and "character," or body. The length of the fiber is of special importance since this property determines to a large extent the kind of fabric that can be made from it. The importance of the length of fiber, or lint, is reflected in the price paid for different lengths of lint on the cotton exchanges throughout the world.

The length of fiber, although a varietal characteristic, is influenced by environmental conditions, especially the amount of moisture in the soil during the period the fibers are developing. It is thought that the fertility of the soil also influences the length of fiber, but so far as the writers are aware no definite data on the effect of fertilizers on the length of lint have been reported. Since the length of lint is of great economic importance, studies were begun at the Texas Agricultural Experiment Station several years ago to determine the effect of fertilizers on the length and other properties of cotton fibers. It is the object of this paper to report some of the results on the length of lint obtained in these studies.

METHODS

The work reported here was conducted on the Experiment Station farm, College Station, and at Substation No. 2, Troup, Texas. The

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Technical Paper No. 238. Received for publication January 20, 1933.

[2]Chief, Division of Agronomy, and Agronomist, respectively.

different analyses of fertilizer were used at the rate of 400 pounds per acre and the 4-12-4 fertilizer was applied also at rates of 200, 400, 600, and 800 pounds per acre. Mebane cotton (Texas Station No. 804), which is one of the best varieties for Texas, was used in the work at both points. The plats were not replicated.

The experiment was conducted by tagging a large number of flowers on each plat on specified dates and collecting the bolls resulting from these flowers when the bolls had matured and opened. The tags served to identify the bolls and in this way it was known that all bolls tagged on a certain date developed under identical weather conditions

TAGGING FLOWERS AND HARVESTING BOLLS

After the cotton had begun to flower actively, 200 freshly opened flowers were tagged at random on each plat at intervals of 7 to 10 days, depending upon the weather conditions during the flowering period. The open bolls were cut from the standing stalks, placed in paper bags, and taken to the laboratory In general, 50 to 125 bolls were obtained from each date of tagging, a number probably sufficient to reflect accurately the effect of fertilizers and rainfall on the length of fiber.

DETERMINING THE LENGTH OF FIBER

The length of lint was obtained by taking a normal lock from each boll and combing out the lint on the seed in the middle of the lock. The combed lint was removed from the seed and laid on a black velvet board and the lint measured to the nearest millimeter. The length of lint obtained in this way for each fertilizer at each date represented 50 to 125 individual measurements.

It is recognized that personal error occurs in measuring the length of cotton fibers. So far as the writers are aware, however, the extent of this error has not been previously determined.

In order to determine the error involved in measuring the length of fiber, 100 bolls of cotton were selected at random and a normal lock taken from each boll. The lint on one of the middle pair of seed of this lock was combed out, removed from the seed, and measured four times, but not consecutively. A total of 400 individual measurements, therefore, were made on which the error of measurement was computed.

In a statistical analysis according to the variance method used by Fisher,[3] the standard deviation of the accuracy of single measurements was 0.534 mm. The probable error of the accuracy of single measurements, which should not be confused with the probable error of random sampling, is 0.6745 of the standard deviation, or 0.360 mm. This means that when a given length of lint in this study is recorded, for example as 25 mm, there is an even chance that the true length is between 24.64 and 25.36 mm. This variation in the length of lint is due to the personal error in making the measurements, and this fact should be taken into consideration in analyzing the data presented in this paper.

[3]FISHER, R. A. Statistical Methods for Research Workers. Ed. 2, London: Oliver and Boyd. 1928.

EFFECT OF FERTILIZERS ON LENGTH OF FIBER

RESULTS OBTAINED AT COLLEGE STATION

The experiment at College Station was conducted in 1927, 1928, and 1929 on Lufkin fine sandy loam soil, which is an extensive soil of the region. This soil is low in nitrogen, phosphoric acid, and potash, and naturally is not very productive. It has responded better to applications of phosphoric acid and potash than to applications of nitrogen, as indicated by the yield of cotton.

The average yearly rainfall at College Station is 38.33 inches. During the growing season of cotton, from April to September, the average monthly rainfall in inches for 43 years has been as follows: April, 4.10; May, 4.81; June, 3.21; July, 2.48; August, 2.36; and September, 2.57. The daily rainfall during the growing season of cotton in 1927, 1928, and 1929 is given in Table 4.

The effect of fertilizer treatments on the length of fiber is shown in Tables 1 and 3. When the results in 1927 are considered by dates, the effect of fertilizers was rather variable and apparently inconsistent (Table 1). However, when the average results for the year are considered, nitrogen appeared to have considerable effect on the length of fiber. For example, all of the plats which received nitrogen in varying amounts, when grouped together, produced lint $1.15 \pm .14$ mm longer than the plat which received no nitrogen but which received phosphoric acid and potash (0–12–4 analysis), as shown in Table 3.

In 1928, most of the fertilized plats produced slightly longer lint than the unfertilized plats (Table 1). This may be due to the fact that the plats which received phosphoric acid in varying amounts, as a group, produced significantly longer lint than the plats which received no phosphoric acid but which received nitrogen and potash (Table 3). Apparently nitrogen and potash had no significant effect on length of lint under 1928 conditions.

In 1929, again most of the fertilizer treatments produced longer fiber than the unfertilized plats (Table 1). For the bolls dated July 15, all of the fertilizer treatments produced considerably longer fiber than the untreated soil. Further, among the bolls dated July 22, only two treatments, the 600 pounds of 4–12–4 and the 800 pounds of 8–12–8 per acre, made longer fibers than the unfertilized soil. Differences in the moisture content of the soil among the various plats on the different dates could possibly have been responsible for this behavior.

As an average for the 3 years at College Station all of the fertilized plats, except those which received 600 pounds per acre of a 4–12–4 fertilizer, produced slightly longer lint than the unfertilized plats (Table 1). The differences in favor of the fertilizer treatments, however, were small, averaging less than 0.50 mm. These small differences, while statistically significant in some cases, are not large enough to be detected in the commercial classing of cotton.

Apparently the average length of fiber for the 3 years at College Station tended to increase as the percentage of nitrogen was increased (Table 1). However, when the results of the plats which

TABLE 1.—*Length of fiber at different dates at College Station, 1927, 1928, and 1929.*

Fertilizer treatment	Mean length of fiber (lint) in mm								
	1927		1928			1929			
	July 11	July 25	July 6	July 16	July 26	July 8	July 15	July 22	Average
None	22.75±.11	21.26±.25	20.97±.11	19.15±.22	19.78±.31	20.75±.37	21.92±.21	23.60±.38	21.44±.08
8-12-8 (800 lbs.)	22.25±.11	20.31±.23	20.91±.13	18.70±.16	20.71±.23	21.34±.20	24.11±.19	24.16±.23	21.48±.08
0-12-4	21.51±.19	20.21±.18	21.50±.09	20.82±.21	19.00±.38	21.54±.32	24.52±.16	23.59±.14	21.73±.08
4-12-4	21.32±.13	21.48±.19	22.25±.15	21.10±.25	21.00±.69	22.79±.33	22.58±.27	21.64±.25	21.88±.07
4*-12-4	22.68±.10	21.60±.25	20.82±.12	19.80±.18	19.65±.38	21.60±.25	23.25±.19	23.60±.32	21.80±.08
6-12-4	21.74±.15	21.82±.21	21.35±.12	21.30±.20	20.20±.45	22.00±.37	24.24±.11	22.89±.16	22.02±.07
8-12-4	23.30±.10	20.35±.25	21.07±.13	21.04±.23	20.10±.32	22.80±.26	24.28±.17	23.00±.22	22.17±.08
4-0-4	22.74±.12	20.88±.20	20.59±.11	20.63±.21	19.60±.32	23.20±.47	23.91±.18	22.83±.27	21.68±.08
4-6-4	22.92±.11	21.18±.15	20.21±.13	21.59±.20	20.45±.40	21.40±.16	23.86±.15	22.11±.48	21.73±.08
4-8-4	23.20±.12	21.57±.17	20.99±.12	18.50±.27	20.60±.44	20.50±.44	23.05±.20	23.20±.59	21.60±.09
4-12-4	21.32±.13	21.48±.19	22.25±.15	21.10±.25	21.00±.69	22.79±.33	22.58±.27	21.64±.25	21.88±.07
4-12-0	22.06±.15	21.27±.21	21.77±.12	21.78±.31	21.50±.37	22.33±.27	22.45±.22	23.33±.27	22.03±.07
4-12-2	21.82±.12	20.86±.19	21.53±.12	19.18±.17	21.67±.35	22.74±.28	22.69±.13	22.47±.37	21.55±.07
4-12-4	21.32±.13	21.48±.19	22.25±.15	21.10±.25	21.00±.69	22.79±.33	22.58±.27	21.64±.25	21.88±.07
200 lbs. 4-12-4	22.20±.14	20.70±.20	21.64±.14	19.63±.19	19.30±.51	20.23±.34	24.00±.22	23.08±.46	21.63±.09
400 lbs. 4-12-4	21.32±.13	21.48±.19	22.25±.15	21.10±.25	21.00±.69	22.79±.33	22.58±.27	21.64±.25	21.88±.07
600 lbs. 4-12-4	22.15±.15	20.59±.19	20.82±.13	19.31±.24	19.87±.29	21.25±.15	23.55±.18	24.25±.48	21.38±.08
800 lbs. 4-12-4	22.42±.12	20.34±.21	21.38±.12	19.35±.27	21.47±.30	21.21±.30	23.94±.18	22.71±.28	21.74±.08
8 tons manure	21.78±.13	20.64±.18	21.43±.11	20.53±.20	20.91±.35	22.00±.32	24.19±.18	23.17±.35	21.60±.07
12 tons manure	22.63±.13	21.03±.17	20.39±.09	19.88±.27	19.30±.44	22.81±.31	24.27±.19	23.59±.26	21.85±.08
12 tons manure and 64 lbs. P_2O_5	22.18±.11	21.14±.15	21.78±.09	20.68±.27	19.67±.25	21.84±.25	24.35±.17	23.00±.23	21.94±.07
Average	22.31	20.96	21.19	20.17	20.27	21.80	23.62	23.12	

*One-third of nitrogen in cottonseed meal; two-thirds in sulfate of ammonia.

received nitrogen in various amounts are grouped together and compared with the results of the plats which received no nitrogen, but which received phosphoric acid and potash, the effect of nitrogen was not significant, as shown in Table 3.

The effects of phosphoric acid were variable from year to year. Applications of phosphoric acid produced a significant increase in length of fiber in 1928 and a significant decrease in 1929 (Table 3). When the results of the 3 years are averaged, however, phosphoric acid had no significant effect on the length of fiber.

Applications of potash had a tendency to reduce the length of staple, although the effect was not significant in either of the 3 years, but it approached significance for the average of the 3 years (Table 3).

RESULTS OBTAINED AT TROUP

The work at Troup was conducted in 1929 in connection with the regular fertilizer work with cotton on Kirvin fine sandy loam soil. This soil responds readily to applications of nitrogenous and phosphatic fertilizers, as indicated by the yield of cotton, indicating a deficiency of these elements. Flowers were tagged on July 25, August 1, and August 8.

The average yearly rainfall at Troup is 42.69 inches. The average monthly rainfall in inches during the growing period of cotton for 27 years was as follows: April, 4.87; May, 4.94; June, 3.00; July, 3.45; August, 2.48; and September, 2.39. The daily rainfall during the growing season of cotton at Troup is given in Table 5.

There were some significant differences in the length of fiber produced on the variously treated plats at Troup, but apparently there was no consistent relation between the length of fiber and the amount of nitrogen, of potash, or of rates of application of the 4–12–4 fertilizer (Table 2). For example, in the bolls dated July 25, the fiber produced on the untreated plats was longer than the average length of fiber from all of the plats. On the other hand, with the bolls dated August 1, all of the fertilizer plats produced longer lint than the untreated plats.

The application of phosphoric acid to cotton on the Kirvin fine sandy loam soil at Troup had a tendency to increase the length of lint (Table 2). The average length of fibers from all the plats which received phosphoric acid in varying amounts was $0.46 \pm .15$ mm longer than the average length of fibers from the plats which received nitrogen and potash but no phosphoric acid (Table 3). When considered in this way the difference approaches significance, but it should be kept in mind that the effect of phosphoric acid was not consistent for each of the three dates in 1929 and that the results are for one year only.

EFFECT OF RAINFALL ON THE LENGTH OF FIBER

The environmental conditions during the growing season apparently exerted considerable influence on the length of fiber at College Station. In 1927, the average length of fiber of bolls dated July 11, was 22.31 mm, or 1.35 mm longer than fiber of bolls dated July 25 (Table 1). This difference is significant, the odds being

TABLE 2.—*Length of lint at different dates at Troup, 1929.*

Fertilizer treatments	Mean length of lint, mm			Average
	July 25	August 1	August 8	
None	23.48±.16	23.21±.27	24.53±.21	23.76±.13
0-12-4	23.45±.19	23.66±.21	24.11±.28	23.71±.15
4-12-4	23.55±.24	25.25±.23	25.25±.19	24.42±.16
4*-12-4	23.35±.23	24.00±.32	24.92±.48	23.73±.18
6-12-4	22.94±.22	24.11±.21	24.75±.47	23.48±.15
8-12-4	22.72±.17	23.37±.30	25.42±.28	23.39±.15
4-0-4	22.79±.22	23.47±.16	24.60±.22	23.67±.13
4-6-4	23.88±.15	24.14±.24	24.77±.27	24.20±.12
4-8-4	23.80±.15	23.65±.18	23.71±.52	23.74±.13
4-12-4	23.55±.24	25.25±.23	25.25±.19	24.42±.16
4-12-0	23.51±.19	23.87±.20	23.95±.31	23.72±.13
4-12-2	22.76±.25	23.78±.18	23.31±.38	23.18±.14
4-12-4	23.55±.24	25.25±.23	25.25±.19	24.42±.16
200 lbs. 4-12-4	23.62±.21	23.83±.27	25.50±.32	24.01±.14
400 lbs. 4-12-4	23.55±.24	25.25±.23	25.25±.19	24 42±.16
600 lbs. 4-12-4	23.25±.14	24.41±.26	25.54±.59	23.87±.15
800 lbs. 4-12-4	23.64±.26	24.21±.29	26.00±.53	23.97±.19
Average	23.34	23.93	24.74	

*One-third of nitrogen supplied in cottonseed meal; two-thirds in sulfate of ammonia.

TABLE 3.—*Effect of nitrogen, phosphoric acid, and potash on the length of cotton fiber.*

Fertilizer treatment	Mean length of lint in mm				
	College Station				Troup, 1929
	1927	1928	1929	Average	
None	22.29±.10	20.36±.11	22.28±.19	21.44±.08	23.76±.13
0-12-4	20.86±.13	21.17±.09	23.44±.18	21.73±.08	23.71±.15
Average of 4-12-4, 4*-12-4, 6-12-4, and 8-12-4	22.01±.06	21.22±.05	23.06±.07	21.97±.04	23.73±.08
Difference	1.15±.14	0.05±.10	0.38±.19	0.24±.09	0.02±.17
4-0-4	22.13±.12	20.57±.10	23.47±.17	21.68±.08	23.67±.13
Average of 4-6-4, 4-8-4, and 4-12-4	22.08±.07	21.05±.07	22.54±.11	21.76±.05	24.13±.08
Difference	0.05±.14	0.48±.12	0.93±.20	0.08±.09	0.46±.15
4-12-0	21.83±.13	21.78±.10	22.64±.14	22.03±.07	23.72±.13
Average of 4-12-2 and 4-12-4	21.45±.08	21.44±.07	22.53±.10	21.72±.05	23.75±.11
Difference	0.38±.15	0.34±.12	0.11±.17	0.31±.09	0.03±.17

*One-third of nitrogen supplied in cottonseed meal; two-thirds in sulfate of ammonia.

TABLE 4.—*Daily precipitation in inches during June, July, August, and September at College Station for 1927, 1928, and 1929.*

Day of month	1927				1928				1929			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.	June	July	Aug.	Sept.
1		0.95						0.25				
2		0.28			0.18							
3		0.10								3.27		
4		1.35			0.51					0.73		
5										0.82		
6	0.40					0.06						
7	0.13					2.69	0.78					
8				0.18		0.24		0.57				
9		0.01						0.10			0.01	
10					0.86					0.03		
11												
12												
13	0.02				0.10					0.02		
14	1.26				0.25							
15				0.08	0.86			0.03				
16		0.06						0.09				0.10
17												
18	0.02											
19	0.19											
20				0.31								
21	2.49		0.02									
22	0.02							0.04		0.15	0.02	
23		0.25						0.25		0.08		
24		0.47			0.02	0.08	0.07				0.44	
25					0.87	0.91			0.01			
26					0.98	0.59		0.04		0.58		
27				0.14		0.03		0.08		0.23		
28	0.07						0.15		0.18			
29	0.41						0.21		0.05			
30												
31							0.12			0.04		
Monthly total	5.01	3.47	0.02	0.71	4.63	4.60	1.33	1.45	0.24	5.95	0.47	0.10
Total for year	41.28				34.34				48.40			

over 10,000:1 that it is not due to chance. This difference in length of fiber was probably due to the rainfall of 2.68 inches July 1 to 4 (Table 4). In 1928, the bolls from flowers dated July 6 had significantly longer fiber than bolls from the flowers dated on July 16 or July 26, as shown in Table 1. This difference may be due to the rainfall of 2.69 inches on July 7 (Table 4). In 1929, however, there did not appear to be any consistent relation between the amount of rainfall and the length of fiber.

The length of fiber increased as the season advanced at Troup, although there was no effective rainfall from July 6 until August 24, as shown in Table 5. The average length of lint of bolls from flowers dated August 8 was 24.74 mm, or 1.40 mm longer than the fiber of bolls from flowers dated July 25 (Table 2). This is a significant difference, the odds being over 10,000:1 that the difference is not due to chance alone. Apparently conditions during the latter part of the growing season were more favorable than the conditions during the early part of the season for development of the fibers, although the amount of rainfall did not seem to be the controlling factor.

TABLE 5.—*Daily precipitation in inches during June, July, August, and September at Troup, 1929.*

Day of month	June	July	Aug.	Sept.
1				
2		T		
3	0.90	1.60		T
4	T*	2.00		
5	0.52	0.06		0.07
6				
7				T
8			T	2.25
9				
10		T		1.03
11				
12		T		
13	0.03		0.03	0.38
14	T			
15				
16				0.13
17				0.02
18	T	T		
19				
20				
21				
22				
23	T	T		
24	0.11	T	0.46	
25				
26		0.06		
27				
28	T			T
29	T			
30				
31				
Monthly total	1.56	3.72	0.49	3.88
Yearly total	47.50			

*T = Trace.

SUMMARY AND CONCLUSIONS

When the average results for the 3 years on the Lufkin fine sandy loam soil are considered, there did not appear to be any significant correlation between the percentage of nitrogen, phosphoric acid, or potash and the length of cotton fiber. However, there was a slight tendency for the potash to reduce the length of fiber. Nitrogen and potash had no appreciable effect on the length of fiber on the Kirvin fine sandy loam. Applications of phosphoric acid, however, increased the length of lint to some extent, which approached significance. While some of the fertilizers appeared to produce significant increases or decreases in length of lint, it is probable that these differences, though significant statistically in some cases, are not large enough to be detected in the commercial classing of cotton.

The length of fiber at College Station was positively correlated with the amount of rainfall during the time the bolls were developing in 2 of the 3 years of the experiment. There was, however, no correlation apparent between the rainfall and the length of fiber during the 1 year of the work at Troup.

THE EFFECT OF TILLAGE ON ERADICATION OF COTTON ROOT ROT[1]

H. E. Rea[2]

Several workers have emphasized the importance of host plants in the maintenance and spread of the cotton root-rot disease, *Phymatotrichum omnivorum* (Shear) Duggar (5, 7, 10, 11, 12).[3] With a view of eradicating these host plants, various tillage operations have been suggested and recommended as a means of reducing the losses from the disease. As early as 1907, Shear and Miles (8, 9) reported a reduction of the disease following deep plowing of infected areas. Taubenhaus and Killough (10) later failed to find depth of plowing an important factor, but recommended types of tillage designed to eradicate host plants of the disease from infected fields. One-year fallow with repeated tillage operations was suggested as a means of eradicating host plants. Reynolds and Killough (7) emphasize tillage operations in their report that the effectiveness of crop rotations in controlling root rot was dependent largely upon the clean cultivation given the crops in the rotations. McNamara and Hooton (5) obtained inconsistent results with 1-year fallow in reducing root rot infections, but indicated that a longer period showed promise.

As a part of an extensive series of investigations on the cotton root rot disease, the Texas Agricultural Experiment Station began several field experiments with farmers in different parts of the Blackland Prairie region of Texas in November, 1927, to obtain further and more definite information of the effect of tillage on the development and

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Technical Paper No. 245. Received for publication January 28, 1933.
[2]Agronomist.
[3]Reference by number is to "Literature Cited," p. 771.

control of cotton root rot. This tillage work was based on the assumption that the cotton root-rot disease was carried over from one year to the next primarily on the live roots of cotton and other host plants. Although the root-rot fungus produces spores, very little is known of their function and it remains to be proved that they can reproduce the disease (10, 11, 12, 14). More recent work, however, has shown that a vegetative resting stage of the fungus, known as the sclerotial stage, is also produced and is an important means of propagating the disease.

METHOD OF CONDUCTING THE EXPERIMENTS

The cooperative experiments were conducted in widely separated sections of the Blackland region of Texas. The northern portion of the region was represented by tests located near Rockwall, Lancaster, and Waxahachie; the central portion by tests near Itasca and Taylor; and the southern by a test at Converse near San Antonio. The fields in which the tests were located were planted to cotton in 1927 and were seriously infected with cotton root rot (Table 1). All of the tests except the one at Lancaster, which was on Bell clay, were on typical Houston black clay.

TILLAGE TREATMENTS USED

In contrast to the common method used on the continuous cotton areas the soil of several other areas was given extensive tillage to the depth of 6 inches over winter, summer, 12-month, and 24-month periods prior to planting cotton. Single plats of each treatment were used in the separate tests and the usual size of plat was ½ acre. At Lancaster and Converse the plats were 1 acre in size. Below is given a brief description of the treatment used on the various plats in the test.

TABLE 1.—*Percentage of root rot in 1927 on cooperative tillage experiments.*

Location	Type of tillage				
	Continuous cotton	Winter tillage	Summer tillage	12-month tillage	24-month tillage
Rockwall	7.8	69.7	79.7	63.7	59.5
Waxahachie	96.0	Not used	92.5	75.0	50.0
Lancaster	68.2	68.0	82.7	52.0	56.4
Itasca	27.0	38.0	34.0	36.0	35.0
Taylor	43.2	38.5	40.6	43.5	39.7
Converse	50.0	Not used	50.0	50.0	Not used

Continuous cotton.—The seedbed on these plats was prepared with a middle-breaker plow in the late fall and cotton was planted and cultivated in 1928, 1929, and 1930, using the prevailing practices.

Winter tillage.—The soil on the winter tillage plat was listed weekly during November and December, 1927, and the test crop of cotton was grown in 1928.

Summer tillage.—These plats were listed and relisted with a middle-breaker plow in December 1927, harrowed level, and immediately sown to oats. Listing of the soil at weekly intervals was commenced

in July after the oats harvest and continued through December, 1928. The test crop of cotton was grown in 1929.

Twelve-month tillage.—The soil on these plats was listed at weekly intervals from December, 1927, to December, 1928. The test crop of cotton was grown in 1929.

Twenty-four-month tillage.—Weekly listing of the soil on these plats was given from December, 1927, to December, 1929, and the test crop of cotton was grown in 1930

RECORDS OBTAINED

Records were obtained each year of the prevalence of cotton root rot and of the host plants of the disease. The extent of root-rot infection was determined by the number of cotton plants killed by the disease and this observation was converted to the percentage of the total number of cotton plants per plat The presence or absence of live roots of cotton and other host plants of the root-rot fungus was determined by digging trenches across the cotton row; each excavation being 3 feet wide, 6 feet long, and 18 inches deep. The results were expressed as the percentage of the total number of excavations in which live roots were found.

EXPERIMENTAL RESULTS

WINTER TILLAGE

The winter-tilled plats had live roots of host plants persisting in 66.7% of the samples of soil examined as compared with 83.3% on the continuous cotton plats in May, 1928, as shown in Table 2.

TABLE 2.—*Percentage of samples containing live roots of root-rot susceptible plants.*

Date of samples	Type of tillage				
	Check	Winter	Summer	12-month	24-month
	Cotton or Perennial Weeds				
May 1928	83.3	66.7	87.5	75.8	75.8
Oct. 1928	1928 cotton growing		55.6	24.3	24.3
May 1929	77.8		27.8	22.2	8.3
	Cotton				
May 1928	55.6	50.0	87.5	41.9	41.9
Oct. 1928	1928 cotton growing		33.3	9.1	9.1
May 1929	66.7		5.6	5.6	0.0
	Perennial Weeds				
May 1928	27.8	41.6	16.6	41.9	41.9
Oct. 1928	1928 cotton growing		27.8	18.2	18.2
May 1929	27.8		22.7	16.7	8.3

Live cotton roots of the previous year's crop were found in 50.0 and 55.6% of the samples taken from the winter-tilled and continuous cotton plats, respectively. Live roots of perennial host plants were found more frequently on the winter-tilled than on the continuous cotton plats. The percentages were 41.6 and 27.8, respectively. Perennial weeds on the winter plats were confined to the tests

located at Lancaster and Taylor. *Physalis mollis* (soft groundcherry) and *Ipomoea trifida* (common tievine) were both found at Lancaster, while only a limited number of *I. trifida* was found at Taylor. These perennial weeds were also found on the other treatments at Lancaster, Waxahachie, and Taylor.

Inasmuch as the extra winter tillage did not create a very great difference in live root carry-over when compared with ordinary treatment (continuous cotton), it was not expected that the root-rot carry-over would be greatly different. Especially at Lancaster and Taylor it would appear that root rot had as great an opportunity to be brought over on the winter-tilled plats as on the plats of continuous cotton. From Table 3 it may be seen that winter tillage did not consistently reduce the root-rot losses. Out of four trials two of the winter-tilled plats showed more root rot than their checks and two less. In 1928, the percentage of root rot on the winter-tilled plats and their respective checks were as follows: Rockwall, 7.5 and 6.7; Taylor, 15.1 and 20.3; Itasca, 16.8 and 20.6; and Lancaster 28.8 and 22.6.

SUMMER TILLAGE

Summer tillage reduced the carry-over of live roots as shown in Table 2. From May to October, 1928, the percentage of live roots persisting, including cotton and perennial weeds, was reduced from 87.5 to 55.6. The continuation of the tillage during the fall and early winter accomplished a further reduction to 27.8% by May, 1929. The greatest reduction was in the abundance of live cotton roots from 87.5% in May, 1928, to 5.6% in May, 1929. On the other hand, the percentages for perennial weeds showed just as many, if not more, roots at the last observation as the first.

The extent of root-rot infections on the summer-tilled and continuous cotton plats for 1929 is given in Table 3. The percentages of root-rot infection for the summer-tilled plats and their checks, respectively, were as follows: Rockwall, 0.2 and 2.7; Itasca, 1.3 and 12.4; Lancaster, 9.0 and 13.3; Taylor, 15.3 and 42.1; Waxahachie, 33.9 and 58.7; and Converse, 65.0 and 68.0. Thus, on all the tests, summer tillage was followed by a reduction in the amount of root rot and in the tests at Itasca, Lancaster, Taylor, and Waxahachie the reduction was considerable. The root-rot infections in the tests at Rockwall were too small and losses were too extensive on the plats at Converse to accept the small reductions as significant.

TWELVE-MONTH TILLAGE

Twelve months of repeated tillage appreciably reduced the stand of susceptible plants. As indicated in Table 2, only 75.8% of the samples from the treated plats in May, 1928, contained live roots of susceptible plants as compared with 83.3% of the samples from the continuous cotton plats. The continuation of the tillage until May, 1929, reduced the relative number of live roots to 22.2%. As was the case with less drastic tillage treatments, live cotton roots were eradicated more rapidly than perennial weeds on the 12-month tillage plats. Live cotton and perennial weed roots were found in 41.9% of the samples taken from the 12-month plats in May, 1928,

as compared with 5.6 and 16.7% of the samples taken in May, 1929, for cotton and perennial weeds, respectively. While the winter and summer tillage treatments were not drastic enough to eradicate perennial weeds, the 12 months of tillage showed a decided reduction.

The plats tilled for 12 months were planted to cotton in 1929 and the percentages of root rot occurring on these plats are given in Table 3. The percentages of root rot on the 12-month tilled and continuous cotton plats, respectively, were as follows: Itasca, 0.1 and 12.4; Rockwall, 0.2 and 2.7; Taylor, 1.9 and 42.1; Lancaster, 8.8 and 13.3; Waxahachie, 55.3 and 58.7; and Converse, 65.0 and 68.0. Although 12 months of tillage eradicated the host plants more completely than summer tillage, there was little difference in the root-rot losses sustained by these two treatments. Also, the association of root-rot losses with the prevalence of host plants on the 12-month tillage plats was inconsistent from test to test. Perennial weeds survived the 12-month treatment on the test at Taylor, yet the apparent control of the disease was outstanding. In view of the large number of susceptible plants present during the entire test, percentages of root rot for the Lancaster test were surprisingly low. The prevalence of host plants in the Waxahachie test was considerably less than at Lancaster, yet the root-rot losses were much higher at Waxahachie. The root-rot losses at Converse were extensive and clearly out of line with the presence of host plants.

TWENTY-FOUR-MONTH TILLAGE

Originally the 24-month tillage treatment was included at five locations, but early in 1929 this treatment was abandoned in the Lancaster test because of interruption in the tillage schedule. In May, 1929, only 8.3% of the samples from the 24-month plats examined showed live roots of any susceptible plant (Table 2). Of the samples of soil examined for live roots from the other type of treatments, 77.8% from the plats in continuous cotton contained live roots, 27.8% from the summer-tilled plats, and 22.2% from the 12-month-tilled plats. Furthermore, only perennial weed roots were found in the May, 1929, samples from the 24-month plats. Thus, the condition of the 24-month plats was such as to expect definite control of root rot if the eradication and reduction of plant carriers would accomplish control.

The root-rot infections for 1930 were very low and the results of the 24-month tillage treatments were inconsistent and failed to indicate any pronounced association of reduction of host plants with the control of root rot. As shown in Table 3, the percentages of root rot for the 24-month tilled plats and their checks, respectively, were as follows: Rockwall, 1.5 and 1.6; Taylor, 2.5 and 7.7; Itasca, 5.1 and 4.2; and Waxahachie, 9.2 and 4.3. The Rockwall and Itasca tests were not only free of perennial weeds at the beginning of the test, but the 24-month tillage treatment eradicated live cotton roots. Yet practically no difference in the percentage of root rot existed between the treated and check plats on the Rockwall test. Similar results were obtained at Itasca. The Waxahachie and Taylor tests both had some perennial weeds surviving the tillage, although out-

standing control of root rot was secured at Taylor. Of the four tests, those at Taylor and Itasca were probably of greatest interest. Control of the disease was secured at Taylor under an infestation of perennial weeds, while at Itasca, where all host plants had been eradicated, control was lacking.

ROOT-ROT SCLEROTIA

The unusually early appearance of a high root-rot infection in 1929 following the 12-months of tillage on the Converse test attracted special attention and an extensive study was made on this test during the summer. The first appearance of the disease on the plat which was tilled for 12 months was noted on June 8, and by June 29, 12% of the plants were dead. The infection had increased to 30.0% by July 15 and, as has already been mentioned, 65.0% of the plants on this plat were killed before frost (Table 3).

TABLE 3.—*Percentage of root rot on tillage experiments, 1928 to 1930.*

Location	1928		1929			1930	
	Continuous cotton	Winter tillage	Continuous cotton	Summer tillage	12-month tillage	Continuous cotton	24-month tillage
Rockwall..	6.7	7.5	2.7	0.2	0.2	1.6	1.5
Waxahachie	13.8	—	58.7	33.9	55.3	4.3	9.2
Lancaster.	22.6	28.8	13.3	9.0	8.8	41.8	—
Itasca......	20.6	16.8	12.4	1.3	0.1	4.2	5.1
Taylor.....	20.3	15.1	42.1	15.3	1.9	7.7	2.5
Converse...	50.0	—	68.0	65.0	65.0	43.0	—

In September, 1928, King and Loomis (3), working in Arizona, discovered a vegetative resting or sclerotial stage of the cotton root rot-fungus in pure cultures. During the spring of 1929, Neal (6) discovered the root-rot sclerotia at Greenville and San Antonio, Texas, under field conditions. Later, Neal and Taubenhaus made separate reports (2) that normal cotton plants had been infected with root-rot sclerotia produced under natural conditions.

In view of these discoveries an extensive series of excavations were made on the Converse test during July by J. J. Taubenhaus, S. E. Wolff, and the author to investigate the carry-over of the disease on that test. Although the source of the root-rot infections was not definitely established, the preponderance of the evidence was that little or none of it was carried over on live roots of host plants. Sclerotia were collected in these excavations and during the remainder of the summer examinations in many sections of the Blackland Prairie region indicated that sclerotia were of wide occurrence. Sclerotia were found in abundance on most of the tillage tests, a fact which probably accounts for the presence of the root-rot disease where host plants were eradicated.

DISCUSSION

The object of the various tillage operations was to reduce the root-rot infection through the eradication of susceptible plants.

On the plats of continuous cotton which received ordinary tillage, live cotton and perennial weed roots were present throughout the period of the test in about the same proportion as at the beginning. The persistence of the host plants was evident not only by the records of the excavated samples, but also by observations of the above-ground growth. On the plats receiving more than ordinary tillage the destruction of host plants was proportionally greater the more extended and drastic the tillage. Winter tillage reduced the carry-over of live cotton roots, but had little influence on perennial weeds. Summer tillage was equally as effective as the 12-month tillage in reducing the number of live cotton roots, but the longer treatment was more effective in reducing the number of perennial weeds. Live cotton roots were completely eradicated and perennial weeds further reduced in stand by the 24-month tillage. Perennial weeds withstood even the most drastic tillage operations used, but their eradication was proportional to the intensity and duration of the treatment.

The root-rot losses were severe on several of the tillage plats and the change in infection from treatment to treatment was not consistently associated with the reduction in stand of host plants. However, it was evident from the results of these tillage experiments that only a small percentage of the root-rot infections surviving the treatments on those plats which were practically freed of susceptible plants was due to the continuous growth of the fungus on live roots. As mentioned previously, the sclerotia are able to reproduce the root-rot disease. It seems probably that the sclerotia, which matured before the tillage treatments became effective, were largely responsible for the infection found on these plats following the treatment.

Since sclerotia are developed in the vegetative strands of the fungus, it is now known that the live roots of host plants perform an even more significant function in the maintenance of the disease than was formerly thought to be the case (2, 3, 4, 6, 11, 12, 13). With the destruction of the host plants follows the death of the root-rot strands which are dependent on the host for nourishment and the curtailing of additional sclerotial production.

Thus, the results secured in these tillage experiments demonstrated the principle by which host plants and thereby eventually the root-rot disease may be controlled. This principle is clean farming or reducing the stand of host plants to a minimum. This involves at least a more extensive replacement of susceptible crops, such as cotton, by non-susceptible crops, such as corn, oats, and the other grasses, and a continued vigilance in eradicating susceptible weeds.

SUMMARY

Several tillage treatments, including listing at weekly intervals during the winter, during the summer, for 12 months, and for 24 months, were used at a number of points in the Blackland Prairie region of Texas in an effort to control the root-rot disease of cotton. The following conclusions are drawn from the results of these studies:

1. The stand of host plants of the root-rot disease was reduced and eradicated in proportion to the intensity and duration of the tillage treatments

2. Although the change in root-rot infections during the course of these experiments was not consistently associated with the reduction in stand of host plants, it was evident that only a small percentage of the infection surviving the more drastic tillage treatments was carried over on the live roots of host plants.

3. Since the root-rot sclerotia are developed in the vegetative strands of the fungus, it appears likely that the sclerotia matured before the more drastic tillage treatments became effective and were largely responsible for the carry-over of the disease on the plats receiving these treatments.

4. In reducing the stand of host plants in proportion to the severity of the treatments used, these tillage experiments demonstrated that the root-rot disease may eventually be controlled by clean farming.

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NOTE

A RAPID METHOD FOR MAKING SMALL GRAIN HYBRIDS

Cross-fertilized barley seeds in large numbers were produced in the Arlington greenhouse in the winter of 1932-33 by a method which the writer has not seen described.

The spikes are prepared as usual by cutting off the boot leaf below the base of the spike, removing base, tip, and lateral florets and

clipping off the distal 2/5ths of the lemma and palet. The unbroken anthers are removed and the head bagged until the lodicules have separated lemma and palet widely and the stigma shows clearly, usually about 2 days after emasculation. An unemasculated spike of the variety to be used as the male parent is then chosen which shows extruding but undehisced anthers. This spike with the tip held lower than the base, is gently tapped against the tip of the emasculated spike. Pollen from the resulting shower settles in abundance upon the receptive stigmas and the spike is rebagged. A rough estimate of the set can be made the next day by counting the number of flowers which have closed. In a test count of 27 spikes containing 566 flowers, 515 seeds were found, or 91%.

The presence of foreign pollen on the male parent spike may be prevented by bagging enough spikes at the time of awn emergence, so that some may be emasculated when ready and the remainder used as pollen parents when the emasculated flowers are well opened.

While this method has been used only on barley, it seems likely to succeed upon wheat and rye, and possibly rice as well.—MERRITT N. POPE, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C.*

BOOK REVIEWS

THE CULTIVATED PLANTS OF MEXICO, GUATEMALA, AND COLOMBIA

By S. M. Bukasov. With supplementary articles by N. N. Kuleshov, N. E. Zhiteneva, V. I. Mazkievicz, and G. M. Popova. Supplement 47 to the Bulletin of Applied Botany, Genetics, and Plant-Breeding. Leningrad. XXXVII + 553 pages, 365 photographs and maps. 1930. Now obtainable through library exchange agreement only. The work is in Russian with an 83-page English summary.

This extensive work, based upon the expedition of the Leningrad Institute of Applied Botany to Central and South America in 1925–26, contains much of interest to the American agronomist not available from other sources. The keynote of the book—as in an earlier work of the Institute on Agricultural Afghanistan—is an investigation of the varietal composition and distribution of the cultivated plants of the region. Interpretations are made as to the probable centers of origin in America of the plants studied. Some 5,000 specimens, including hundreds of samples of maize, beans, potatoes, and other important food plants, were taken to Russia for the purpose of studying their economic value.

The work contains sections on the following: Centers of origin of the cultivated plants of America; complex of cultivated plants of northern tropical America and altitudinal limits of cultivated plants; maize, teosinte, quinoa, beans, cotton, potato, tuber crops of the potato zone, and root crops of the hot and temperate zones; Solonaceous garden crops, including the capsicums, lycopersicons and physalis; cucurbitaceous crops; oleiferous and technical plants, including chea, sunflower, tobacco, cocoa, agave, and cacti; native fruit crops, including anona, zapote, injerto, caimito, mamey, papaya,

pineapple, avocado, and others; cultivated plants of old world origin, including cereals, leguminosae, oleiferous, cucurbitaceous, and fruit plants; cottons of Mexico, Guatemala, and Colombia; and cottons of Venezuela, West Indies, Panama, and the Providencia Islands.

The book is fully indexed and offers much new material regarding the characteristics and distribution in Central and South America of the above-mentioned crops. (G. W. H.)

HANDBUCH DER MOORKUNDE: VOL. VII. AMERICAN PEAT DEPOSITS

By A. P. Dachnowski-Stokes and V. Auer. Berlin: Gebr. Borntraeger. 245 pages, illus. 1933.

This is the "America" volume of a series of books appearing under the general title of "Handbuch der Moorkunde" and dealing with the peat land resources of different countries. The book just issued consists of three parts and presents the fundamental facts and geographic distribution of peat deposits in the United States, southeastern Canada, and southern South America.

The description of peat land in the United States (abbreviated to USA by the editor of the Handbuch) is by Dr. A. P. Dachnowski-Stokes of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture. His contribution comprises 140 pages with 9 plates and 23 text-figures. It is an outgrowth of a wide range of comparative field studies and indicates how peat soils are related to one another and lead up to a new system of classification. The main grouping is associated with dominant environmental conditions of climate, vegetation, and land relief. The subdivisions have been outlined on the basis of inherent developmental and morphological features of distinctive peat profiles and on the degree of decomposition and characteristic properties of peat soils produced in different environments.

The second and third contributions are by Dr. V. Auer, who is well known for his peat investigations in Finland. The author deals with peat areas in southeastern Canada and certain parts of South America. The treatment of Canadian peat deposits make possible a comparison with Finnish and other northern European types of peat land. The description of areas in South America, more particularly those of Tiera del Fuego, presents new features and relationships.

The book has been written for scientists whose interest lies in soils and agronomy, but it will be of value to the geographer, ecologist, geologist, and the practical worker concerned with agricultural, industrial, and other uses of peat land.

The first two parts of the book are published in the English language, while the third part is in German. The volume is issued under the editorship of Dr. K. von Bülow. The subscription price for bound copies is RM. 24.30, but the book may be purchased separately at RM. 30.50. (A. G. M.)

AGRONOMIC AFFAIRS

MEETING OF THE NORTHEASTERN SECTION

The Northeastern Section of the Society held its 1933 meeting at Windsor and Storrs, Conn., and at Kingston, R. I., on June 26 and 27. Tours of inspection were made of field plat and lysimeter work at these three points. The business meeting of the Section was held at Storrs on the evening of June 26, when the following committees reported: Fertilizer Ratios, A. B. Beaumont; Soil Organic Matter, M. F. Morgan; Pasture Research, B. A. Brown; and Forage Crops, J. S. Owens.

The following officers were elected: M. H. Cubbon, Massachusetts State College, *President;* J. A. Bizzell, Cornell University, *Vice-President;* and R. P. Thomas, University of Maryland, *Secretary-Treasurer.* A mimeographed report of the meeting and containing the committee reports as prepared by H. C. Swift, University of Maine, retiring *Secretary,* is available for distribution. The Section received an invitation to hold its 1934 meeting at the University of Maine.

MEETING OF THE NORTHEASTERN SECTION WITH SECTION O OF THE A. A. A. S.

The Northeastern Section of the Society will meet with Section O (Agriculture) of the American Association for the Advancement of Science in Boston on December 28. The program will consist of a symposium on "Field and Microchemical Methods for Determining Soil Deficiencies," and has been arranged by Dr. T. E. Odland, Dr. M. F. Morgan, and Prof. M. H. Cubbon.

Those appearing on the symposium include Prof. C. H. Spurway of Michigan, Prof. R. H. Bray of Illinois, Prof. M. H. Lockwood of Massachusetts, Dr. Emil Truog of Wisconsin, Dr. S. F. Thornton of Indiana, and Prof. L. G. Willis of North Carolina.

NEWS ITEMS

H. W. Reuszer, formerly with the New Jersey Agricultural Experiment Station, has been appointed soil bacteriologist at the Colorado Agricultural Experiment Station, Fort Collins, Colo.

S. S. Obenshain has been appointed to take charge of the soil survey work at the Virginia Agricultural Experiment Station. He succeeds G. W. Patteson, who resigned to enter land appraisal work for the Federal Land Bank of Baltimore, Maryland.

P. D. Spilsbury, who has been doing graduate work in plant breeding at Iowa State College for the past two years, has accepted a position at Dixie College, St. George, Utah, where he is teaching the work in agronomy.

Ernest L. Mayton has accepted a fellowship in the Department of Agronomy, Vermont Agricultural College. He will pursue graduate work toward a Master's degree under Dr. A. R. Midgley.

JOURNAL

OF THE

American Society of Agronomy

Vol. 25 | December, 1933 | No. 12

AN OUTLOOK[1]

M. A. McCall[2]

What follows is not new or profound It has no official significance It is merely a sketch of certain personal views growing out of an attempt to adjust concepts of professional relationships to these changing times

We agronomists in common with all others who are responsible in any degree for directing thought in this country are "on the spot" Our nation is blessed with resources and materials necessary for physical welfare and presumably for human happiness to a degree never before vouchsafed to mankind. In spite of these blessings we are faced with economic and social disorder We have not known collectively how to use our wealth so that all have profited from it. There is tragedy in our failure to prevent the situation in which we find ourselves. If as a people we do not devise a successful solution, it will be a most damning reflection on our intelligence.

On no group of our people does responsibility rest more heavily during this period than on our scientists They have made possible most of our material advances. They must assist in gaining control of that which they have created. They must help to work out a system for making their creation produce its equivalent in human values. We in agronomic science must assume our share of this responsibility. We have had our part in creating the elements of the problem. We must play our part in adjusting them in its final solution.

One short generation back, Sir William Crookes drew his famous picture of a world pinched by hunger. His specter of famine has been destroyed. There is potential abundance for all. Yet in spite of this abundance the actual picture we face is almost as pathetic as his predicted one. Undigested abundance has produced economic and social dyspepsia.

Our ability to produce has outrun the ability of our economic machinery to assimilate and make usable that which we produce. The finally successful method for solving the problem cannot now be pre-

[1]Presidential address presented at the twenty-sixth annual meeting of the Society held in Chicago, Ill., November, 1933.

[2]Principal Agronomist in charge, U. S. Dept. of Agriculture, Washington, D C.

dicted. Intelligence suggests, however, that any successful plan must provide for a production which can be absorbed and which does not build up a market-destroying surplus. This means a planned economy. The first steps toward a planned national agriculture already are under way.

Stability is essential for the success of a planned agriculture. This is true for economic reasons, and for reasons of public safety. The food supply of our people must be safeguarded. Without stability of production, surpluses cannot safely be reduced or want may result. For the world as a whole, seasonal fluctuations in agricultural production are usually so well scattered and so off-set one another from year to year, that total production is remarkably stable This is not true, however, for any one country. In the United States we normally produce wheat in excess of our needs, but in 1933 our crop was 150,000,000 bushels less than normal disappearance. Seasonal variations of this type are the most potent factors in reducing stability. Fluctuations from such sources are only partly within our control. Extension of our agriculture into marginal areas, where heat and drouth are likely to occur, however, has increased instability from this cause. Gradual withdrawal from such areas can increase certainty of production. We, also, can increase stability by removing fluctuations due to preventable hazards. Poorly adapted crops and varieties, diseases, insect pests, poor cultural practices, low fertility, all are factors in instability which we can control. The effective conquest of these factors depends on science and research. This defines our part as agronomists in the program.

If a planned production is accepted as a probable feature of our future economic system, it is obvious that the plan must be nation wide in scope. There must be one plan for the entire country. Separate plans for each state are impossible.

It is equally obvious to any well-informed person that the scientific basis for a planned agriculture must be constantly reinforced by research to supply information and materials not now available. To be effective in supporting a unit program, this research output also must be coordinate, as though coming from a single source. Charged with the obligation to supply the scientific ground work, we agronomists are equally obligated to insure its necessary unity. It is a challenge we cannot evade.

Using present facilities, a unit national research program can be effected in either of two ways It can be developed entirely within the United States Department of Agriculture. Alternately, it can be developed by coordinating the programs of the Department and the state stations. The first alternative possesses certain very definite disadvantages. Developed to the extent necessary to cover all functions and areas, it would mean an immense unwieldy bureaucracy repugnant to American ideals. It would decrease the intimacy of contact with local conditions on the part of responsible officials so necessary in planning and decision. It would lead to duplication of work. By removing local responsibility it would be undemocratic. The second alternative allows for much greater efficiency in the use of facilities. It eliminates duplication of per-

sonnel and equipment. It brings the intimate knowledge of local problems into planning and interpretation. It produces more for less money. It is effective, however, only in so far as individual units can work together.

Historically we Americans are individualists. Our institutions have developed and grown in this spirit Each state agricultural experiment station program began as a separate unit, distinct from all others, and all distinct from the Federal Department Each worker began as an individual, considering his work and its results personal property not to be violated or interfered with by others. Recognition of the benefits derived from interchange of ideas and materials, and the unusually highly developed sense of service and duty in our workers, have gone far in breaking down some of the inhibitions of our individualistic beginning Cooperation between the state stations and the Federal Department has eliminated some duplication, and has effected some degree of coordination But we have not gone far enough to remove all unjustifiable duplication nor to produce a unit national program.

Coordination of research to be effective must be based on cooperation between the Federal Department and all the state stations concerned in a given problem. The cooperation should be between individual state stations as well as between the stations and the Federal Department. This should be officially recognized. All units in the cooperation must take part in planning, in executing, in interpreting, and in final recommendation and use. The obligations are joint and so should be the program To be consistent with our national philosophy, the entire relationship should be democratic As a trained group in a body politic committed to democracy, it is an obligation to apply the principle successfully in our own work.

The determining factor in successful cooperation is the individual worker. Cooperation cannot be legislated or forced. It can come only through a will to cooperate. This latter results from a proper perspective of the social significance of our work, and from a realization of the advantage of cooperation to us as individuals. It is hindered by certain false ideas that have persisted from the individualistic origins of the scientist's ethics.

The importance of individual initiative in a successful research program is axiomatic. Originality is individual. Many of our most productive researchers are so strongly individual that it is virtually impossible for them to work with others. Such men must in the public interest be protected and allowed to work in their own way. Administrators must adjust them into the scheme of things so as to use them effectively. Because men of this type established the foundations of science, there has grown up a belief that all workers in science have a right to work in this same way. This is well enough for productive genius, but most of us unfortunately do not carry that divine spark. We cannot produce effectively except in the team under some more able leader. It may be a bitter pill, but we must realize that desire is not ability. The methods justified for genius cannot be accepted for mediocrity. In the expenditure of public funds there must be value received, and administrators must see that

we work so as to produce. The foregoing does not mean that the place of the average man is not important. Most of our total advance comes from small accretions contributed by a host of minor workers. There is always a place for such in the research structure. Their value and usefulness must be recognized. They must be given their opportunity within their limitations. They in turn must realize these limitations, and play the game accordingly. Nor should one so limited feel that this precludes advancement. Effective team play is just as valuable as individual genius, and should be as well rewarded. Successful administrators recognize this fact.

For the rank and file of us, effective cooperation is also a most effective protection. In a group attack we can produce results and insure support, where singly most of us would not succeed.

Recognition for his results is an important part of every scientist's reward. Monetary advancement depends on such recognition. To insure recognition there is a strong temptation to secrecy until data are finally safeguarded by publication. This tendency begets suspicion, makes cooperation difficult, and holds back progress. Free interchange of information and material is itself a most effective protection. When the father of an idea is generally known, the idea cannot well be taken by another. No one can afford the stigma of widely known plagiarism. Free intercourse and interchange of ideas beget widespread personal friendships, also a most effective safeguard

While the will to cooperate is the most essential factor in insuring success in cooperative relations, administrators can do much to make cooperation easier. They can devise administrative safeguards and can develop a machinery of cooperation which will remove many impediments. They can insist on proper ethical standards. They can make effective cooperation worth while.

One strong incentive to cooperation can almost be taken for granted in our agronomist group. In no unit of society is the sense of public duty more highly developed The acceptance of this responsibility insures an honest effort toward whatever seems best in the public interest. If convinced cooperation is correct we may rest assured our agronomists will whole-heartedly put it into effect.

In this country our important advances in mass coordination have always come under the stress of a national crisis. This has been true of agricultural research as of everything else. The first real beginning in this latter field came during the World War. Present chaos may force us even farther along the way. It must if we are to serve as we are capable of serving.

Historically the last frontier is gone. In human progress, however, there is no last frontier. Adventure is always before us. To achieve it as always requires vision and fortitude. We cannot admit less of these qualities than possessed by our forefathers who conquered the old frontier. Let us go into this adventure all together.

BORDER EFFECT STUDIES OF RED CLOVER AND ALFALFA[1]

E. A. HOLLOWELL and DAVID HEUSINKVELD[2]

The errors involved in border effect and their importance have been given little consideration in the technic of harvesting experimental plats of forage crops in the humid eastern states. Although investigators working with cereal plats have published widely, only meager information on the effect of borders on the yields of forage plats is available. In the Great Plains states, where moisture is the principal limiting factor for maximum forage production, border effect on forage plats is usually so pronounced that the error is apparent and the border surrounding the plat is discarded before results are secured. In Canada, McRostie and Hamilton[3] have shown that yields of broadcast seeded plats, with 1-foot borders included, may contain errors which are not constant as between varieties for the year reported These results were secured from plats surrounded by a 2-foot alley, however the plat size was not mentioned.

In the development of a technic to minimize experimental error, border effect is a source of error that may be of importance in the accuracy of plat yields, and in addition influences the amount of space and time needed in handling the experimental plat. Furthermore, the question arises as to the number of rows in drilled plats that should be removed to increase the accuracy if border effect is a source of error.

PROCEDURE

This experiment was conducted at the Northwestern Ohio Agricultural Experiment Station, Holgate, Ohio, during the seasons 1930 to 1932, inclusive. The soil of this experiment station is a Brookston clay loam, heavy phase, and is apparently very homogeneous for field soils as is evident from the yields of check plats of this and other experiments. In the years 1929, 1930, and 1931, solid seedings of Ohio red clover No. 15808 and Grimm alfalfa No. 15936, Ohio red clover No. 16031 and Grimm alfalfa No. 15993, and Ohio red clover No. 16031 and Grimm alfalfa No. 19135, respectively, were made. These seedings were 10-drill widths and 100 feet in length and were made with a drill having 20 delivery tubes 4 inches apart. Calibration tests were made on the amount of seed delivered by each individual spout of the drill to determine the variability and accuracy of the machine. The seedings were made in the spring of each of the respective years, except the 1929 alfalfa seeding which was made in the fall. The plants of this 1929 fall seeding were badly heaved and killed during the winter, and results were not secured for that plant-

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Agronomy Department, Ohio Agricultural Experiment Station; tests conducted at Holgate, Ohio. Also presented at the annual meeting of the Society held at Washington, D. C., November 16, 1932. Received for publication January 26, 1933.

[2]Agronomist and Assistant Agronomist, respectively.

[3]McROSTIE, G. P., and HAMILTON, R. I., The accurate determination of dry matter in forage crops. Jour. Amer. Soc. Agron., 19: 243–251. 1927.

ing. Otherwise, excellent stands were secured each year. The legume seedings were made with a companion crop of Fulghum oats for the first 2 years and of Wayne oats for the third, at the rate of 1 bushel per acre drilled crosswise of the legume seedings. The oats were harvested for grain. The clover and alfalfa seedings ran in an east to west direction as was necessitated by the position of the ranges.

During the early summer, rows were cut out of the solid seedings to make 8-, 12-, and 16-inch alleys. Two rows on each side of an 8-inch alley, three rows on each side of a 12-inch alley, and four rows on each side of a 16-inch alley, together with their respective alleys, constituted the various plats studied in this experiment. Check plats consisted of seven consecutive rows. The rows were 4 inches apart and 15 feet in length, except for the length of the plats of the first cutting of red clover in 1930 which were 16.5 feet instead of 15 feet. These plats were replicated 19 times and systematically arranged to represent the soil area and to occur as nearly as possible an equal number of times on all the rows of the clover drill. Besides the plats including 12- and 16-inch alleys, two series with 8-inch alleys were formed with the object that the alley of one would be cultivated when necessary to be kept free from weeds, while the other alley would not be cultivated. Weeds did not grow in any of the alleys, however, and none were cultivated. During the last of August the entire area was clipped to destroy developing weed seeds.

Two cuttings were made of each legume the second year by harvesting each individual row separately with a hand sickle. In order to avoid variations in height of stubble, all cuttings were made even with the surface of the soil. The ends of the plat rows and the overlapping drill rows which resulted from the meeting of the drill widths in solid seedings were discarded. The green material from each row was placed in a muslin bag and the bags taken collectively to a drier twice a day as they were harvested. The samples were left in the drying room under temperatures of 140° to 180°F, until the moisture content of the material reached a point where decomposition would not occur. In 1930, the dried samples were reduced to a moisture-free basis, while in 1931 and 1932 approximately only 5% were reduced to this basis. A factor was calculated and applied to the remaining samples which had been preheated along with the 5% as these were comparable in the amount of moisture they contained.

Height measurements and observations on plant development were made previous to each harvest. The yields of replicate rows were averaged and probable errors of the means were calculated. The probable significance of the differences in yield between different rows was determined from probability integral and Fisher's "T" tables.[4]

RESULTS

The results of these studies may best be analyzed by an examination of Figs. 1 and 2, which graphically illustrate the data. That border effect is very pronounced on plants in rows adjacent to the 12-

[4]FISHER, R. A. Statistical Methods for Research Workers. Edinburgh: Oliver and Boyd, Ed. 2. 1928.

and 16-inch alleys and in some cases on plants bordering on the 8-inch alleys is clearly indicated. As the width of the alleys decreases, competition between plants of the border rows increases, resulting

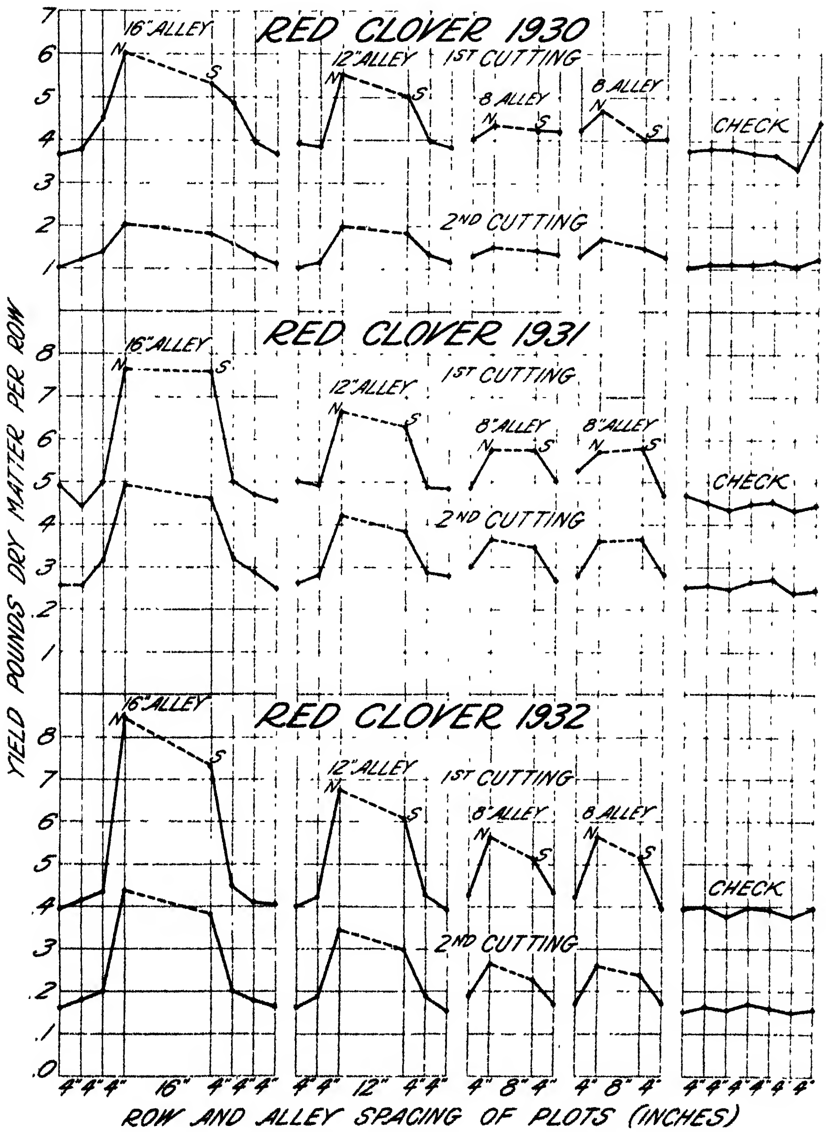

FIG. 1.—Comparison of border effect in red clover plats with alleys of different widths, Holgate, Ohio, 1930–32.

in a uniform diminution of border effect. With the exception of the 1931 results with red clover, the rows bordering on the north side of the alley gave greater yields than those on the south side. This is

particularly true of the rows bordering on the 12- and 16-inch alleys, but it is also evident in the rows bordering on the 8-inch alleys. The largest border effect on the red clover plats occurred during the season of 1932, while the greatest yields were produced in 1931.

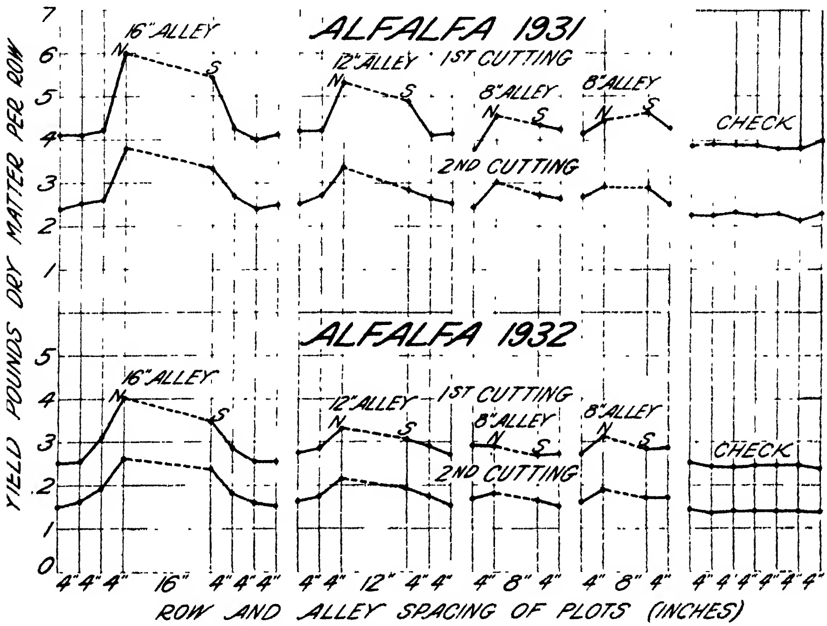

FIG. 2.—Comparison of border effect in alfalfa plats with alleys of different widths, Holgate, Ohio, 1931 and 1932.

1930 RESULTS

The season of 1930 was characterized by a heavy rainfall in April and a shortage of moisture during the succeeding months of May, June, and July. From the data presented in Tables 1, 2, and 3, the significance of the apparent differences between the yields of plants from adjacent rows was calculated, and it was found that they were significant between the first and second rows and between the second and third rows of the first cutting and significant only between the first and second rows of the second cutting. While the trend of greater yields is apparent, the difference in yields between the north and south rows of all alleys is not statistically significant. During this abnormally dry year the growth of the plants was rather irregular, however, no differences in height occurred between the plants of rows next to alleys and the plants in other rows. Upon close examination the plants in the rows adjacent to the alleys appeared to have made a greater leaf development from the crown than plants of inside rows. The above observations and lack of difference in height occurred in all years, except for the second cutting of red clover and alfalfa in 1932. Plants of this cutting in rows next to alleys were 2 to 3 inches higher than those of inside rows and showed more leaf development from the crowns of the plants.

Table 1.—*Average yield in pounds of dry matter of red clover and alfalfa rows in relation to their position with respect to 16-inch alleys, Holgate, Ohio, 1930–32.**

Year	Cutting	Position of rows from alley							
		North side				South side			
		4th row	3rd row	2nd row	Next to alley	Next to alley	2nd row	3rd row	4th row
					Red Clover				
1930	1st.	.368±.0132	.380±.0060	.453±.0149	.606±.0164	.531±.0140	.484±.0111	.395±.0125	.370±.0142
	2nd.	.104±.0031	.122±.0031	.140±.0059	.207± 0097	.182±.0061	.160± 0064	.130±.0062	.110±.0043
1931	1st.	.494±.0140	.443±.0074	.506±.0095	.764±.0152	.758±.0142	.503±.0126	.470±.0086	.454±.0071
	2nd	.254±.0059	.257±.0064	.318±.0069	.493±.0110	.460±.0110	319± 0120	.285±.0064	.250±.0093
1932	1st.	.395±.0069	.414±.0061	.437±.0101	.844±.0129	.733±.0137	.451±.0078	.411±.0063	.406±.0072
	2nd.	.160±.0037	.178±.0040	.200±.0039	439±.0081	.385±.0069	.201±.0053	.179±.0044	.165±.0055
					Alfalfa				
1931	1st.	.411±.0083	.412±.0081	.422±.0090	.601±.0112	.539±.0094	.428±.0070	.400±.0060	.407±.0083
	2nd.	.240±.0040	.254±.0059	.262±.0039	.382±.0084	.336±.0078	.270± 0051	.240±.0031	.250±.0053
1932	1st.	.251±.0082	.254±.0089	.312±.0091	.403±.0130	.350±.0103	.285± 0072	.266±.0061	.257±.0077
	2nd.	.150±.0039	.161±.0031	.192±.0036	.264±.0058	.239±.0045	.181±.0037	.160±.0031	.155±.0025

*Rows 4 inches apart and 15 feet long, except for 1st cutting in 1930 which were 16 5 feet long.

TABLE 2.—*Average yield in pounds of dry matter of red clover and alfalfa rows in relation to their position with respect to alleys of different widths, Holgate, Ohio, 1930–32.**

Year	Cutting	Position of rows from alley									
		12-inch alley						8-inch alley (a)			
		North side			South side			North side		South side	
		3d row	2nd row	Next to alley	Next to alley	2nd row	3rd row	2nd row	Next to alley	Next to alley	2nd row
		Red Clover									
1930	1st	.392 ± .0093	.383 ±.0082	.552 ±.0093	.504 ±.0153	.396 ±.0085	.382 ±.0106	.403 ±.0070	.436 ±.0089	.423 ±.0127	.422 ±.0099
	2nd .	.105 ±.0025	.114 ±.0018	.198 ±.0060	.185 ±.0064	.132 ±.0044	113 ± 0036	.131 ±.0032	.151 ±.0048	.142 ±.0040	.133 ±.0043
1931	1st . ..	.500 ±.0130	.490 ±.0094	.666 ±.0091	.630 ±.0112	.488 ±.0087	.485 ±.0082	.483 ±.0090	.573 ±.0096	.576 ±.0092	.502 ±.0089
	2nd. ..	.262 ±.0079	.282 ±.0057	.421 ±.0105	.385 ±.0062	.289 ±.0076	.278 ±.0085	.296 ±.0053	.366 ±.0045	.358 ±.0079	.269 ±.0059
1932	1st...	.401 ±.0086	.420 ±.0078	.674 ±.0109	.608 ±.0103	.426 ±.0079	.392 ±.0076	.426 ±.0084	.567 ±.0122	.517 ±.0115	.431 ±.0073
	2nd. .	.162 ±.0040	.187 ±.0049	.343 ±.0064	.299 ±.0043	.185 ±.0049	.155 ±.0042	.187 ±.0048	.265 ±.0095	.229 ±.0071	.172 ±.0044
		Alfalfa									
1931	1st ..	.422 ±.0074	.420 ±.0056	.536 ±.0102	.492 ±.0099	.412 ±.0071	.416 ±.0053	.374 ±.0064	.456 ±.0087	.435 ±.0080	.424 ±.0083
	2nd. ..	.252 ±.0055	.271 ±.0047	.338 ±.0071	.287 ± 0074	.261 ±.0029	.253 ±.0027	.243 ±.0048	.301 ±.0061	.271 ±.0062	.264 ±.0048
1932	1st	.275 ±.0108	.287 ±.0090	.333 ±.0110	.306 ±.0108	.290 ±.0094	.270 ±.0087	291 ±.0071	.289 ±.0093	.266 ±.0065	.272 ±.0106
	2nd....	.163 ±.0049	.172 ±.0038	.217 ±.0051	.197 ±.0053	.175 ±.0038	.157 ±.0035	.169 ±.0030	.182 ±.0045	.166 ±.0027	.157 ±.0033

*Rows 4 inches apart and 15 feet long, except for 1st cutting in 1930 which were 16.5 feet long.

TABLE 3.—*Average yield in pounds of dry matter of red clover and alfalfa rows in relation to their position with respect to alleys of different widths. Holgate, Ohio, 1930–32.**

Year	Cutting	8-inch alley (b), position of rows from alley				Check, Position of rows to each other						
		North side		South side								
		2nd row	Next to alley	Next to alley	2nd row	1st row	2nd row	3rd row	4th row	5th row	6th row	7th row
						Red Clover						
1930	1st	.425 ±.0115	.472 ±.0122	.401 ±.0080	403 ±.0084	.378 ±.0115	.382 ±.0072	.380 ±.0092	.370 ±.0075	.367 ±.0075	.333 ±.0088	.448 ±.0137
	2nd	.130 ±.0055	.172 ±.0065	.149 ±.0038	.127 ±.0036	106 ±.0037	.111 ±.0042	.111 ±.0041	.110 ±.0042	.116 ±.0037	.106 ±.0044	.124 ±.0043
1931	1st	.526 ±.0115	.570 ±.0091	.580 ±.0105	.467 ±.0103	.469 ±.0090	.453 ±.0094	.436 ±.0090	.448 ±.0071	.455 ±.0069	.433 ±.0070	.461 ±.0087
	2nd	.276 ±.0066	.362 ±.0100	.367 ±.0079	.281 ±.0071	.252 ±.0064	.255 ±.0061	.249 ±.0054	.266 ±.0074	.272 ±.0037	.240 ±.0037	.245 ±.0068
1932	1st	.423 ±.0097	.564 ±.0082	.516 ±.0108	.397 ±.0076	.393 ±.0063	400 ±.0075	.376 ±.0074	.399 ±.0050	.395 ±.0072	.379 ±.0050	.398 ±.0083
	2nd	.170 ±.0059	.258 ±.0066	.239 ±.0058	.170 ±.0037	.152 ±.0044	.163 ±.0042	.156 ±.0036	.170 ±.0042	.162 ±.0033	.151 ±.0048	.157 ±.0041
						Alfalfa						
1931	1st	.416 ±.0077	.447 ±.0083	.465 ±.0068	.427 ±.0077	.387 ±.0086	.392 ±.0067	.390 ±.0064	.387 ±.0046	.380 ±.0065	.380 ±.0059	.400 ±.0059
	2nd	.266 ±.0058	294 ±.0077	.289 ±.0066	.251 ±.0048	.225 ±.0044	.225 ±.0054	.231 ±.0038	.225 ±.0046	.229 ±.0042	.212 ±.0039	.228 ±.0032
1932	1st	.270 ±.0078	.312 ±.0093	.282 ±.0098	.285 ±.0080	.252 ±.0074	.242 ±.0071	.238 ±.0072	.243 ±.0066	.243 ±.0067	.243 ±.0076	.237 ±.0077
	2nd	.161 ±.0032	190 ±.0044	.170 ±.0043	.171 ±.0034	.144 ±.0021	.137 ±.0027	.139 ±.0029	.139 ±.0027	.139 ±.0029	.138 ±.0031	.136 ±.0028

*Rows 4 inches apart and 15 feet long, except for 1st cutting in 1930 which were 16.5 feet long.

TABLE 4.—*Percentage increase in yield of plats with borders over plats without borders; results of border effect study applied to plats 90 ft. by 6⅔ ft., or 1/72.6 acre in size.*

Year	16-inch alley		12-inch alley		8-inch alley	
	1st cutting, %	2nd cutting, %	1st cutting, %	2nd cutting, %	1st cutting, %	2nd cutting, %
			Red Clover			
1930	7.2	11.6	4.3	8.1	2.2	4.9
1931	8.7	11.9	6.1	7.7	3.7	5.4
1932	12.3	20.0	7.4	11.9	4.8	6.8
			Alfalfa			
1931	6.7	9.6	4.8	6.9	1.8	4.0
1932	8.7	14.0	6.2	8.9	3.0	4.1

1931 RESULTS

In 1931, as in 1930, the yields of the border rows adjacent to the alleys were much greater than those from the second row. In some cases, however, considerable differences occurred between the yields of the second and third rows from the alleys. Although differences in yields of red clover between the north and south rows adjacent to alleys are evident, these differences are not statistically significant. This situation is reversed with alfalfa, however. In fact, the difference exists not only in plats with 12- and 16-inch alleys, but to some degree in plats with 8-inch alleys as well. The rainfall during the 1931 growing season was well distributed. Heavy rains fell during the early part of June and about the middle of July, thus furnishing the plants with an optimum supply of moisture at critical periods.

1932 RESULTS

In 1932, border effect of the red clover plats was greater than in any of the previous years under test It is thought that this may be explained in part by an analysis of rainfall records. Significant differences in yield between all north and south rows of all alleys occurred this season with the exception of the second cutting of one of the series of plats with 8-inch alleys. In a few cases plants in the second row from the alley produced greater yields than those in the third row and these differences were significant.

With alfalfa, however, calculated odds failed to show a large difference between the north and south rows adjacent to the alleys, although the trend is similar to that of other years. In the alfalfa plats differences in the yield of plants between the second and third rows occurred in many instances and are particularly significant in the plat with the 16-inch alley.

APPLICATION OF BORDER EFFECT STUDIES TO FIELD PLATS

These studies were conducted with the expectation of applying the results to large plats with different perimeters to determine the percentage of error under field experimental conditions. The method

of sowing experimental plats at this station consists of seeding 1 drill width 100 feet long, with a drill of 20 spouts 4 inches apart. Using the 20-drill rows as a basis for applying the results of the border effect studies, yields of theoretical plats were computed for each year, for each width of alley, and for the first and second cuttings of both red clover and alfalfa. Table 4 presents the computations of the application of these results to field plats of $\frac{1}{72.6}$ acre The average yield of the seven rows of the check plats was used as a basis of determining the yield of the plats without borders. Compared with the yields of this plat were those from 12 rows of checks plus the 8 rows bordering on the 16-inch alley; those from 14 rows of check plat yields plus the 6 rows bordering on the 12-inch alley; and those from 16 rows of check plat yields plus the 4 rows bordering on an 8-inch alley

As the width of alley between plats increases, there is a corresponding increase in the error in the yields because of the inclusion of border rows. A direct correlation between these two relationships is apparent Border effect in all instances resulted in a greater error in the second cutting than in the first, although a consistent variation between the first and second cuttings for any single year is not evident from the data. Wide variations in error occurred between the data of different years, as is shown by a comparison of the results of 1930 and 1932.

DISCUSSION

Although border effect may not be apparent to the eye, the results of this study show that under the conditions of the experiments it does exist in appreciable amounts and is a source of error in the accurate determination of forage crop plat yields. While the argument may be presented that the effect is relative on all plats in any one series of tests, this is rarely the case because of a variation in reduction in plant population between different varieties and sources. As is shown by the results, the amount of border effect diminishes with a lessening of the width of the alleys between plats. If only 8-inch alleys are left between plats, the possible error may reach as high as 6.8% if $\frac{1}{72}$ acre plats are considered. Furthermore, a space of more than 8 inches between plats is desirable to define clearly the boundary of the plat in order to expedite the harvesting of any experimental series, and with machine seeding it is practically impossible to maintain a uniform distance between plats. With the wide variation of errors between the first and second cuttings of a single year and between different years, the feasibility of applying a correction factor becomes very remote. While inherent errors, such of soil variability, are to be expected, there is no reason to countenance experimental errors which may be avoided; and one of these errors is border effect.

The fact that the north row out-yielded the south row of the same alley is a phenomenon which has not been satisfactorily explained.

It is evident from the results of 1931 with red clover that with an optimum rainfall this difference is not apparent, although such is not the case with alfalfa. At this latitude the plants of the north row of an alley are subjected to greater light intensities for greater periods than plants of the south row. Whether the additional light intensity increases the rate of transpiration of the plants in the north row over those in the south row is questionable, for it is in the year approaching optimum moisture that the plants of the south row produce yields nearly equalling those of the north row. With such conflicting evidence it is thought possible that the balance between vegetative and root development which to some degree may be influenced by the amount of effective rainfall during the winter and early spring months is to a great extent the controlling factor. While the light needed for photosynthesis in both rows would be in excess of that required, the additional light intensity received by the plants of the north row may encourage the development of a greater number of leaf buds from the crowns of the plants of the north row. Further studies will be undertaken in an effort to explain this phenomenon.

While border effect is principally confined to the row adjacent to the alley, in some cases the effect is pronounced in the second row. To discard the two rows next to the alley at harvest would minimize border effect as a source of error in securing yields from experimental plats. While some may question the validity of applying the results of these studies to theoretical yields of large plats, it is felt that the large number of replications and the unusual uniformity of performance as shown by Figs. 1 and 2 and Tables 1, 2, and 3 warrant such application in a consideration of border effect in plats of the size used and under the conditions of the experiment.

SUMMARY

1. Plats composed of 8-, 12-, and 16-inch alleys with two, three, and four rows, respectively, adjacent to each side of the alley, were cut out of solid drill seedings of red clover and alfalfa during the seasons of 1929 to 1931, inclusive. Yields of dry matter of each row were harvested in each of the following years. Results of these studies were applied to theoretical plats of $\frac{1}{72.6}$ acre in size to compare the increase in yields of plats due to the inclusion of border rows over yields of plats excluding borders.

2. Yields of border rows adjacent to 8-, 12-, and 16-inch alleys were with but few exceptions significantly greater than the yields of the second and successive rows and check rows. In several instances the yields of the second rows from alleys were also significantly greater than those of succeeding rows and of check rows.

3. In the majority of the tests, rows bordering on the north side of alleys produced greater yields than those on the south side and calculated odds indicate that many of these differences are significant.

4. As the width of alleys between plats decreased there was a corresponding decrease in the yields of border rows.

5. When the results of these studies were applied to plats of $\frac{1}{72.6}$ acre in size, the inclusion of borders increased the yield from 2.1% to 20% for red clover and from 1.8% to 14.0% for alfalfa.

6. Border effect is greater on the second cutting than the first and varies greatly from year to year.

7. Rainfall appears to be directly correlated with border effect.

8. Under conditions of the experiment the inclusion of border rows in plat yields constitutes an experimental error of such magnitude as to necessitate the removal of border rows before plat yields are secured Such wide variations exist between the effect in different years and cuttings that the application of a correction factor would be of little value in reducing the error.

9. By discarding the two rows next to the alley border effect can be eliminated as a source of error.

BEHAVIOR OF THE JONES LIME REQUIREMENT DETERMINATION WITH PROGRESSIVE DECREASE IN SOIL ACIDITY[1]

W. H. METZGER[2]

In a study of the rates of reaction of certain liming materials with acid soils, decrease in lime requirement, determined by the Jones method (3),[3] was one of the criteria employed. The fact that the decreases observed were frequently smaller than could reasonably be anticipated suggested that the method might be at fault. Carleton (2), Schollenberger (4), and perhaps others have observed in applying the method to soils treated with increasing increments of lime that the change in lime requirement deviates considerably from a linear function of the amount of lime applied. The present paper deals with a study of this relationship.

METHODS

One hundred gram portions of two acid soils, a Canfield silt loam and a Mahoning silty clay loam, placed in flat-bottom pans of 10 inches diameter were treated with increasing increments of standard $Ca(OH)_2$ solution. The plan followed was to add at one time only enough solution to saturate the soil and then permit the soil to dry at room temperature. Further additions of solution or in its stead of distilled water were made, followed by drying until all portions had re-

[1]Part of a thesis presented to the Graduate School of the Ohio State University, Columbus, Ohio, in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication February 3, 1933.

[2]Formerly Assistant, Department of Agronomy, Ohio Agricultural Experiment Station, now Assistant Professor of Soils, Kansas State College, Manhattan, Kan. The author acknowledges his indebtedness to The Columbia Chemical Division of the Pittsburgh Plate Glass Company, donors of the fellowship under which the work was done, and to Professors Robert M. Salter and Richard Bradfield for their interest and guidance.

[3]Reference by number is to "Literature Cited," p. 796.

ceived their quota of lime and all had been wet and dried the same number of times and with the same volume of liquid. Subsequently, carbonated water was added to those samples that had received lime in excess of the lime requirement. These were dried and aerated with an electric fan to remove excess carbon dioxide. The remaining samples were given a similar treatment except that distilled water was employed instead of carbonated water.

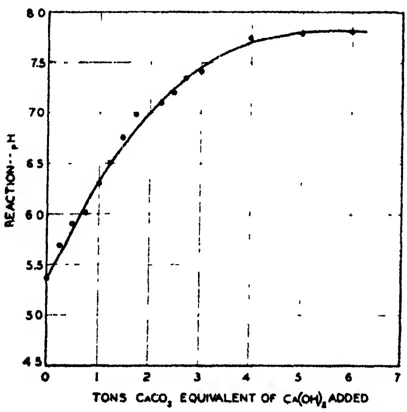

Fig. 1.—Titration curve for Canfield silt loam.

The pH of the soils thus prepared was determined by use of the quinhydrone electrode. Lime requirement was determined by the Jones (3) method as modified by Baver (1), but with some additional changes. Preliminary trials showed that the time of stirring could be reduced from 10 minutes, as proposed by Baver, to 6 minutes and the original Jones factor was employed instead of the leaching method recommended by Baver. The procedure was as follows: To 5.6 grams of air-dry soil in a 250-cc beaker were added 200 cc of a freshly prepared calcium acetate solution containing 0.5 gram of the salt and adjusted to 27° C. After stirring for 6 minutes with a motor-driven stirrer the suspension was filtered, the first 10 to 15 cc of filtrate being returned to the filter in order to obtain a clear extract. A 100-cc aliquot of the filtrate was titrated with N/100 NaOH using phenolphthalein indicator. The value thus obtained was corrected by subtracting the titration value for a blank determination. Lime requirement as pounds $CaCO_3$ equivalent per 2,000,000 pounds of soil was calculated by multiplying the corrected number of cc of N/100 NaOH by the factor 640.

DISCUSSION OF RESULTS

The data for the Canfield soil are presented in Table 1 and those for the Mahoning soil in Table 2. In Figs. 1 and 2, the pH values are plotted against the lime additions, and in Figs. 3 and 4 the lime requirement values are similarly plotted.

It is evident that the data obtained by the modification of the Jones lime requirement method employed fail to agree with the calculated values. The Canfield soil, having an initial Jones lime requirement of 3,648 pounds of $CaCO_3$, still showed a requirement of 1,216 pounds after the addition of lime equivalent to 3,500 pounds of $CaCO_3$. Furthermore, it required 4,352 pounds of lime in excess of the original lime requirement to give a final lime requirement of practically 0. The largest lime addition to the Mahoning soil failed to reduce the lime requirement to 0.

The negative lime requirement values in the columns headed "Jones lime requirement" in Table 1 were determined by titrating the extracts, which were alkaline to phenolphthalein, with standard HCl. The significance of these values is questionable.

TABLE 1.—*Lime requirements and pH values for Canfield silt loam.*

Treatment, lbs. ($CaCO_3$ equiv. per 2,000,000 lbs. soil)	Reaction of treated soil, pH	Reaction of soil-calcium acetate suspension, pH*	Jones lime requirement, lbs. ($CaCO_3$ equiv.)	Lime requirement calculated, lbs. ($CaCO_3$ equiv.)†
0	5.35	6.39	3,648	——
500	5.68	6.53	3,136	3,148
1,000	5.89	6.57	2,752	2,648
1,500	6.01	6.59	2,432	2,148
2,000	6.29	6.64	2,112	1,648
2,500	6.51	6.70	1,728	1,148
3,000	6.75	6.76	1,472	648
3,500	6.98	6.84	1,216	148
4,000	7.08	6.86	1,024	—352‡
4,500	7.10	6.93	704	—852
5,000	7.20	6.97	640	—1,352
5,500	7.34	7.03	512	—1,852
6,000	7.40	7.08	320	—2,352
8,000	7.75	7.20	64	—4,352
10,000	7.80	7.40	—192‡	—6,352
12,000	7.82	7.44	—256	—8,352

*At equilibrium.
†Difference between original lime requirement of soil and the amount of lime added in the treatment.
‡Negative values indicate excess lime.

TABLE 2.—*Lime requirement and pH values of Mahoning silty clay loam.*

Treatment, lbs. ($CaCO_3$ equiv. per 2,000,000 lbs. soil)	Reaction of treated soil, pH	Reaction of soil-calcium acetate-suspension, pH*	Jones lime requirement, lbs. ($CaCO_3$ equiv.)	Lime requirement calculated, lbs. ($CaCO_3$ equiv.)†
0	4.63	6.04	5,696	——
1,000	5.14	6.12	4,928	4,696
2,000	5.46	6.28	3,968	3,696
3,000	5.72	6.32	3,456	2,696
3,500	5.91	6.33	3,136	2,196
4,000	5.99	6.37	2,816	1,696
4,500	6.18	6.39	2,432	1,196
5,000	6.33	6.43	1,984	696
5,500	6.51	6.56	1,536	196
6,000	6.56	6.60	1,344	—304‡
6,500	6.59	6.62	1,216	—804
7,000	6.90	6.80	832	—1,304
8,000	7.10	6.91	512	—2,304

*At equilibrium.
†Difference between original lime requirement of soil and the amount of lime added in the treatment.
‡Negative values indicate excess lime.

Factors affecting the behavior of the Jones lime requirement method with decreasing acidity will now be considered. Carleton (2) attributes its behavior to the fact that the indicator, phenolphthalein, used in the titration does not show color until the reaction approaches pH 9.0. However, this is merely an attempt to explain

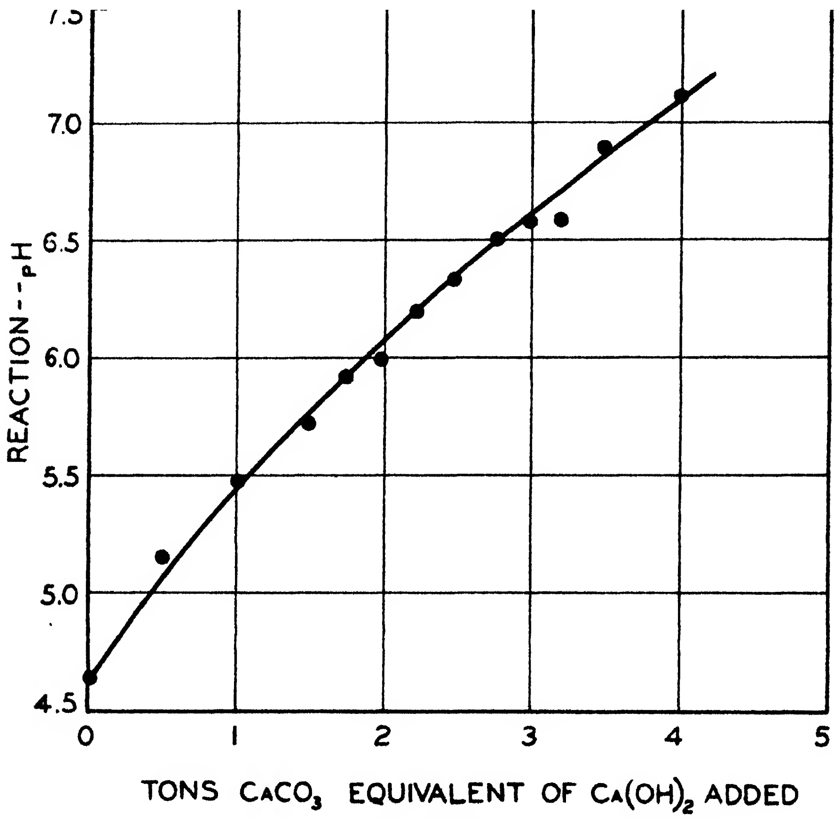

FIG. 2.—Titration curve for Mahoning silty clay loam.

those cases in which the amount of lime indicated by the Jones method brings the soil to pH 7.0, although it still shows a lime requirement after treatment. No such simple explanation appears to suffice.

The reaction of the calcium acetate solution employed, as measured by the quinhydrone electrode, was pH 6.85. Since calcium acetate is the salt of a strong base and a weak acid, a solution of the pure salt would be alkaline as the result of hydrolysis. Hence the solution used must have contained a considerable amount of un-ionized acetic acid. When the exchange complexes of the soil are dispersed in such a solution, two reactions are possible, i. e., the replacement of exchange hydrogen by the calcium ions of the solution and the replacement of exchange calcium by the hydrogen ions of the solution. Since the calcium-ion concentration of the solution is high compared

to its hydrogen-ion concentration, the first reaction may be expected to predominate, yielding an extract of higher titrable acidity than the original solution with soils containing any appreciable amount of exchange hydrogen. As base saturation of the exchange compounds is approached, a point will be reached where the two reactions will

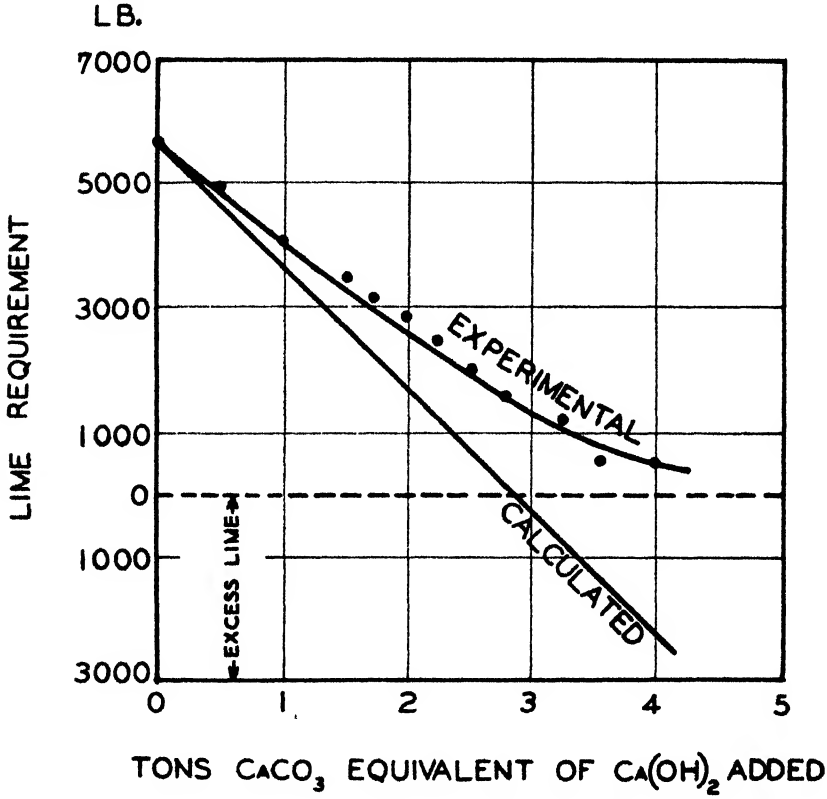

FIG. 3.—Curves showing deviation of lime requirement change from the theoretical, with progressive increase of lime additions to Canfield silt loam.

occur to an equal extent. At this point the titrable acidity of the solution should not change. With still higher degrees of base saturation of the exchange compounds, the second reaction will predominate and the titrable acidity of the solution will be decreased.

From Table 1, it appears that the equilibrium point is reached with the Canfield soil with a lime application approximately equivalent to 8,000 pounds of $CaCO_3$ which gives a soil having a reaction of pH 7.75 by the quinhydrone method. This point, therefore, may be considered the end-point of the Jones lime requirement method instead of the neutral point as ordinarily considered. It is obvious from Figs. 3 and 4, however, that there is no simple relation between the values obtained by the Jones method and the amounts of lime required to bring the soil to the true end point or 0 lime requirement value. Hydrogen ions brought into solution by replacement with cal-

cium will tend to depress the reaction of the calcium acetate solution so that equilibrium is attained at a different reaction with soils of different initial degrees of base saturation.

It may be observed that with those soil samples whose initial pH was above that of the calcium acetate solution the pH of the sus-

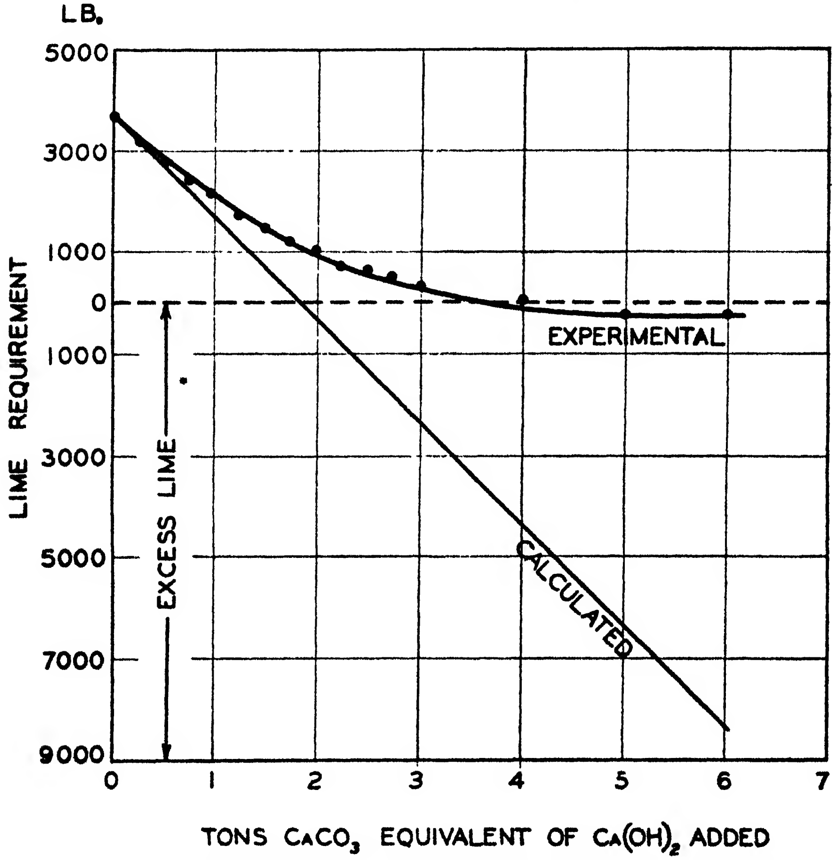

FIG. 4.—Curves showing deviation of lime requirement change from the theoretical, with progressive increase of lime additions to Mahoning silty clay loam.

pension at equilibrium was changed toward greater alkalinity, whereas the titrable acidity of the extract was increased as compared to the original acetate solution. It is difficult to explain this result except by the entrance into the solution of the anion of some acid whose degree of dissociation is less than that of acetic acid. Among such acids is carbonic acid and in the case of those soil samples whose reaction exceeded pH 6.0 bicarbonates may have been brought into solution by the reaction of acetic acid on free carbonates, by the replacement of hydrogen ions from the exchange compounds by calcium ions from the solution, or to a lesser extent, perhaps, directly from the soil. The solubility of bicarbonates would be greater in the salt solution than in pure water.

It is interesting to compare the effects of the various increments of lime applied with the corresponding decreases in Jones lime requirement after correcting the latter for the difference in reaction of the soil-calcium acetate suspensions at equilibrium. For example, in Table 2 the lime requirement of the untreated Mahoning soil is 5,696 pounds of $CaCO_3$ equivalent and the pH of the soil-calcium acetate suspension is 6.04. The same soil treated with lime equivalent to 8,000 pounds of $CaCO_3$ shows a lime requirement of 512 pounds and a pH value for the suspension of 6.91. From the "titration curve" for this soil (Fig. 2), it is estimated that 3,200 pounds of $CaCO_3$ would be required to change its reaction from pH 6.04 to pH 6.91. If this amount be added to the change in lime requirement, 5,184 pounds (5,696 — 512 = 5,184), the value 8,384 pounds is obtained, which agrees fairly well with the amount of lime actually applied, i. e., 8,000 pounds.

Similar calculations were made for each quantity of lime applied to the Mahoning soil and for each application to the Canfield soil up to the point where the measured lime requirement was equal to zero. These are presented in Table 3.

TABLE 3.—*Lime applied compared with decrease in Jones lime requirement plus correction.**

Lime applied, lbs. ($CaCO_3$ equiv. per 2,000,000 lbs. soil)	Decrease in Jones lime requirement plus correction, lbs. ($CaCO_3$ equiv.)	
	Mahoning silty clay loam	Canfield silt loam
500	——	812
1,000	1,042	1,346
1,500	——	1,716
2,000	2,528	2,180
2,500	——	2,720
3,000	3,200	3,176
3,500	3,560	3,732
4,000	4,000	3,974
4,500	4,504	4,544
5,000	5,112	4,758
5,500	5,940	5,136
6,000	6,352	5,528
6,500	6,560	——
7,000	7,624	——
8,000	8,384	6,284

*Correction equals lime required to change pH of soil from that of the suspension of the untreated soil in calcium acetate to that of the suspension of the treated soil. Estimated from the "titration" curves in Figs. 1 and 2.

Examination of the data in Table 3 shows in most cases a good agreement between the amounts of lime applied and the decrease in Jones lime requirement plus the correction. In the higher applications with the Canfield soil the agreement is less satisfactory but this may result, in part at least, from the inaccuracy of the "titration" curve in the range where the quinhydrone electrode becomes unreliable.

SUMMARY

A modification of the Jones lime requirement method was applied to two series of soils, each prepared by treating an originally acid soil with increasing increments of calcium hydroxide. The decrease in lime requirement corresponding to a given treatment with lime was in all cases below the theoretical value. However, a value agreeing fairly well with theory was obtained if the change in Jones lime requirement was increased by the calculated amount of lime needed to change the soil from the pH value of the untreated soil in equilibrium with the calcium acetate solution to the similar pH value for the treated soil. A 0 lime requirement value by the Jones method was not obtained until enough lime had been added to a soil to raise its reaction considerably above pH 7.0.

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THE INFLUENCE OF SOIL PRODUCTIVITY ON THE ORDER OF YIELD IN A VARIETAL TRIAL OF CORN[1]

C. A. MOOERS[2]

In a previous publication,[3] data were presented which showed that the productiveness of the soil was a highly important factor in connection with a varietal trial of corn. For example, a variety ranking high under rich-land conditions might be of inferior rank under poor-land conditions. No experimental data were available, however, at that time from comparable trials on the same type of soil at different levels of fertility, such as might be gotten through manuring. Beginning in 1921, two series of experiments with four varieties of corn have been carried out on a Memphis silt loam soil at the West Tennessee Station, one series on unmanured land of moderate fertility and the other on land manured annually at the rate of 10 tons per acre of farmyard manure in order to increase materially the soil productivity. The data from 11 years of these trials are now available for consideration.

VARIETIES USED

Neal Paymaster, Jellicorse, Jarvis Golden Prolific, and Hickory King were the varieties used. Neal Paymaster is extensively grown throughout the state and has been recommended by the Station

[1]Contribution from the Department of Agronomy, Tennessee Agricultural Experiment Station, Knoxville, Tenn. Received for publication February 3, 1933.

[2]Agronomist.

[3]Jour. Amer. Soc. Agron., 13: 337-352. 1921.

because of its superior yielding capacity on the prevailing types of soil. The Jellicorse variety grows taller than Neal Paymaster, produces from 6 to 10% more stover, and had appeared to be a close rival in grain production, so much so that the data previously obtained in several years of ordinary varietal trials did not satisfactorily

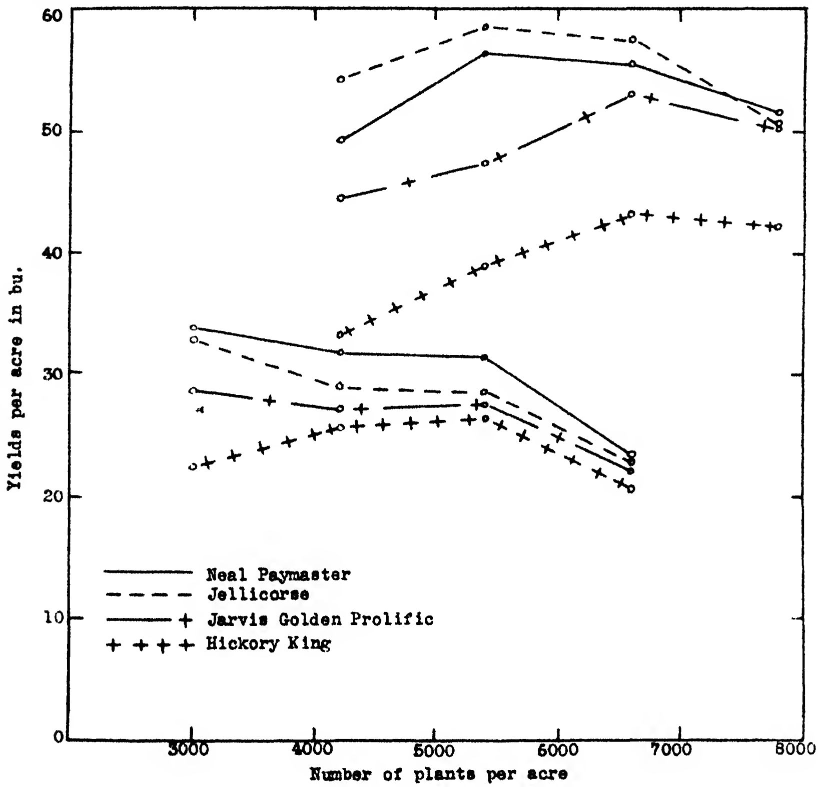

FIG. 1.—Yields of four varieties of corn at different "stands" at each of two levels of soil productivity

determine its relative worth. Jarvis Golden Prolific does not grow as tall as Neal Paymaster, and, as the data in Table 1 show, does not produce as much stover. It is rated as a good yielder among farmers and is widely grown in the state. Hickory King is an old standard variety but is not grown extensively except on "thin" land, i. e., land producing 15 to 25 bushels per acre. In height and stover yield it ranks with Neal Paymaster.

EXPERIMENTAL RATES OF PLANTING OR "STANDS"

In the experimental series the varieties were grown at each of four rates as follows: In series I, on the unmanured land, 3,000, 4,200, 5,400, and 6,600 plants per acre; and in series II, on manured land, 4,200, 5,400, 6,600, and 7,800 plants per acre. A close approximation to these numbers was gotten by planting four times as many seed as

TABLE 1.—*The yield of four varieties of corn as affected both by the number of plants per acre and by the productivity of the soil, average yields from an 11-year trial (1921–32) on Memphis silt loam soil at the West Tennessee Station.*

Variety	3,000 plants		4,200 plants		5,400 plants		6,600 plants		Average of two best rates for grain	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
Series I—Unmanured land										
	Bu.	*Tons*	*Bu.*	*Tons*	*Bu.*	*Tons*	*Bu.*	*Tons*	*Bu.*	*Tons*
Neal Paymaster	33.4	0.97	31.5	1.09	31.2	1.17	23.1	1.39	32.5	1.03
Jellicorse	32.4	1.07	29.0	1.16	28.8	1.33	22.8	1.45	30.7	1.12
Jarvis Golden Prolific	28.8	0.69	27.2	0.93	27.5	0.92	22.2	0.95	28.2	0.81
Hickory King	22.3	0.86	25.8	1.00	26.4	1.04	20.6	1.09	26.1	1.02
Series II—Manured land										
	4,200 plants		5,400 plants		6,600 plants		7,800 plants		Average of two best rates for grain	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
	Bu.	*Tons*	*Bu.*	*Tons*	*Bu.*	*Tons*	*Bu.*	*Tons*	*Bu.*	*Tons*
Neal Paymaster	49.3	1.81	56.3	2.04	55.4	2.17	51.5	2.28	55.9	2.11
Jellicorse	54.1	1.98	58.6	2.19	57.2	2.29	50.6	2.36	57.9	2.24
Jarvis Golden Prolific	44.5	1.53	47.2	1.71	53.0	1.93	50.3	1.80	51.7	1.87
Hickory King	33.0	1.73	39.1	1.95	43.4	2.21	42.2	2.23	42.8	2.22

plants wanted and then thinning to the desired stand. The object in making the trials at various stands was, as far as possible, to overcome probable error from unfair spacing. It is assumed that only when each variety is spaced to produce approximately maximum yields can a fair comparison be made. Jarvis Golden Prolific, for

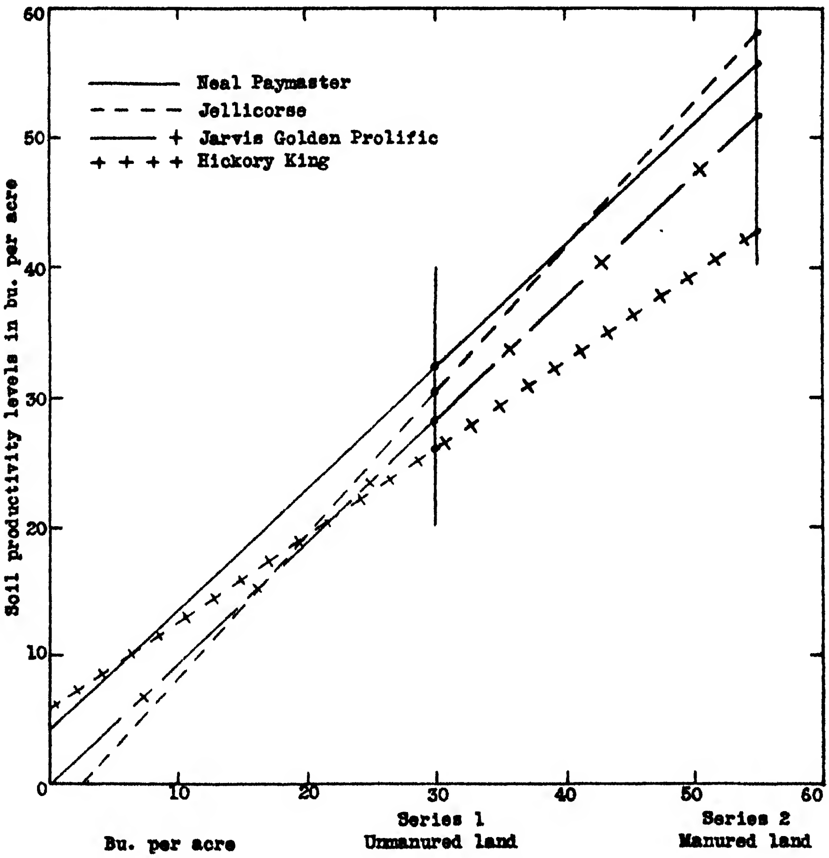

FIG. 2.—Average yields of corn at each of two levels of soil productivity.

example, with its less height and foliage production, would be expected to produce its largest yield at a thicker stand than that best suited to the ranker-growing Jellicorse variety. Moreover, such adjustments are usual in farm practice. Previous experience had shown that the rates selected would probably be ample for the purpose, and, as a matter of fact, they could hardly be improved upon if the experiments were to be repeated.

The average yields obtained in the 11-year period are given in the table and are graphed in Fig. 1. Inspection of the latter shows at once that a decidedly different spacing is required on the unmanured land from that which gave highest yields on the manured land; also that there are differences in the response among the varieties in each

series. On the unmanured section, Neal Paymaster, Jellicorse, and Jarvis Golden Prolific did best at the 3,000 rate and Hickory King at the 5,400 rate, but all gave their lowest yields at the 6,600 rate. On the manured section, Neal Paymaster and Jellicorse yielded best at the 5,400 rate and Jarvis Golden Prolific and Hickory King at the 6,600 rate, and all but Jellicorse gave their lowest yield at the 4,200 rate.

ORDER OF YIELD

For purposes of comparison the yields at the two best rates for grain production were averaged for each variety. The order of yield as thus obtained on the unmanured section is as follows: Neal Paymaster, 1st; Jellicorse, 2d; Jarvis Golden Prolific, 3d; and Hickory King, 4th. It is noteworthy that in this series Neal Paymaster was found to surpass Jellicorse in 8 of the 11 years. In the manured series the order was the same except that Jellicorse came first and Neal Paymaster second. A comparison of the yields year by year showed that in this set Jellicorse outyielded Neal Paymaster in 8 of the 11 years. The Jellicorse variety, therefore, appears to be superior under what may be termed "rich-land" conditions but is surpassed by Neal Paymaster under "poor-land" conditions. A better idea of what the data show may be had from Fig. 2, where the yields for each variety under the two conditions are plotted and connected by a straight line, which is further extended to show the trend. The indications are that up to 40 bushels per acre, or a little more, Neal Paymaster is the heavier yielder, but that on land producing higher yields Jellicorse would be superior. Jarvis Golden Prolific proved in each set to be inferior to either Neal Paymaster or Jellicorse but decidedly superior to Hickory King. The possibility is indicated in Fig. 2, however, of Jarvis Golden Prolific doing no better than Hickory King, or even giving inferior yields, on land producing 20 bushels or less per acre. This last deduction is at least of interest as a possible explanation of the continued use by farmers on very poor land of an apparently inferior variety as judged by either set alone of the data secured.

CONCLUSIONS

The following conclusions appear to be justified by the evidence presented:

1. The "stand," or number of plants per acre, is an important factor in a varietal trial of corn. That is, a "stand" suited to each variety is necessary to a fair comparison.
2. The results of a varietal trial of corn are primarily applicable only to soils similar in productivity to that on which the trial was made.
3. Varietal trials on soils of both high and low productivity are required in order to furnish a comprehensive picture of the adaptability and relative standing of different varieties.

FELLOWS ELECT

RAY IAMS THROCKMORTON

RAY IAMS THROCKMORTON, Kansas State College, Manhattan, Kansas. Born on a farm near Waynesburg, Greene County, Pennsylvania, December 10, 1886. B. S., Pennsylvania State College, 1911; M. S., Kansas State College, 1922. Graduate student and assistant in soils, Cornell University, 1922-23; Assistant in soil survey, Kansas State College, 1911-13; Assistant Professor of Soils, 1913-15; Associate Professor of Agronomy, 1915-18; Professor of Soils, 1918-25; Professor and Head of Department of Agronomy, 1925 - -. Member of A A A. S., Fellow, 1929; American Society of Agronomy; and American Association of Soil Survey Workers. Special interests include education in agronomy, soil management, and land utilization.

Professor Throckmorton has been a member of the Society since 1914 and has served on various committees of the Society and has participated in the programs of many annual meetings He has been a member of the Executive Committee since 1931 and has served as Vice-President of the Society the past year.

RALPH JOHN GARBER

RALPH JOHN GARBER, West Virginia University, Morgantown, West Virginia. Born at Deer Creek, Illinois, April 24, 1890. B. S., University of Illinois, 1912; M. S., University of Minnesota, 1917; Ph.D., University of Minnesota. 1922. Instructor in high school, Morgan, Minnesota, 1913-15; Instructor in high school, Monticello, Minnesota, 1915-16; Assistant Professor of Field Crops, University of Minnesota, 1917-18; Assistant Professor of Plant Breeding, 1918-20; Associate Professor of Agronomy, West Virginia University, 1920-23; Professor and Head of department of Agronomy and Genetics 1923 ——. Member A. A. A. S.; American Society of Agronomy; and Genetics Section, A. A. A. S. His special interest include plant breeding, field plat technic, and statistical methods.

Dr. Garber has served on many special and standing committees of the Society, has participated frequently in the programs at the annual meetings, and has made important contributions to the fields of crop production and plant breeding.

ANDREW R. WHITSON

ANDREW R. WHITSON, University of Wisconsin, Madison, Wisconsin. Born at Stanton, Minnesota, October 9, 1870. B. S., University of Chicago, 1894; pursued graduate studies in geology, chemistry, and botany, University of Chicago, 1894–5 and 1898–1900. Field assistant U. S. Geological Survey, 1892–93; Principal of high school, Beloit, Wisconsin, 1895–98; Assistant Professor of Agricultural Physics, University of Wisconsin, 1900–01; Professor, 1901–05; Professor and Chairman of Department of Soils, 1905– . Delegate to International Agricultural Congress, Vienna, 1907. Author of *Notes on Soils*, *Soils and Soil Fertility* (with Walster), and numerous bulletins and reports. Member A. A. A. S., Wisconsin Academy, American Society of Agronomy, American Soil Survey Association, and International Society of Soil Science. Special interests include nitrification in soils availability and losses of soil phosphates, soil survey, and meteorology.

Professor Whitson is a charter member of the Society, and has served on various committees. From the pioneer days of soil science in this country to the present, Professor Whitson, because of his practical background and broad graduate training in physics, chemistry, geology, and botany, has contributed much to the development of soil science.

MINUTES OF THE TWENTY-SIXTH ANNUAL MEETING OF THE SOCIETY

The annual meeting of the Society was called to order by President M. A. McCall at 9:00 a.m. on Thursday, November 16, at the Stevens Hotel in Chicago, Ill. The general program was given at this session. The annual dinner was held on Thursday evening. Meetings of the Crops and Soils Section were held on Thursday afternoon and on Friday. Almost 300 members and visitors attended the various sessions. An auditing committee was appointed as follows: F. D. Keim, *Chairman*, and F. L. Duley.

COMMITTEE REPORTS

STANDARDIZATION OF FIELD EXPERIMENTS[1]

Chairman T. A. Kiesselbach presented the report of the Committee on Standardization of Field Experiments, which upon motion, was adopted and the Committee discontinued.

It is the purpose of this report to present a revised set of standards for procedure in field and lysimeter experiments together with a revised and enlarged bibliography bearing on these problems. Ten years have elapsed since the original standards were adopted by the Society. More recently several supplements including standards for lysimeter experiments have been officially approved. This 10-year period has been fruitful of many additional researches concerning the conduct of field experiments. These have been studied by this committee and earlier recommendations are herein modified accordingly. Since many of the principles apply equally to both soils and crops experiments, their discussion will be handled as a unit, with distinction made where necessary.

It is the opinion of the committee that the conditions of field experimentation are so variable that the function of a set of standards should be to point out the general principles to be considered rather than to make specific detailed recommendations. The individual investigator may then adapt his technic to his local situation.

All standards heretofore adopted by the Society may be found in Vol. 16, No. 1; Vol. 18, No. 12; and Vol. 22, No. 12, of the Journal. The various additions to the bibliography occur likewise in the following issues of the Journal: Vol. 16, No. 1; Vol. 16, No. 12; Vol. 22, No. 12; Vol. 23, No. 12; and Vol. 24, No. 12.

Subject to the adoption of these Standards by the Society, it is requested that this committee be discharged.

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RECOMMENDED STANDARDS FOR FIELD EXPERIMENTS

Location of experiments.—Field experiments should be so located with respect to soil and climate that the results may by applicable where recommendations

[1]Separate reprints of this report may be obtained from the Secretary of the Society at 10 cents a copy, plus postage.

are to be made. Where experiments are also to be used for public demonstration, consideration should be given to their accessibility.

Uniformity of soil.—The variability of any field should be ascertained previous to beginning experiments therein. If the history of the land as to system of cropping and soil treatment is not known, it should be tested by a uniform system of cropping for one or more years until its suitability for the purpose is established. The lay of the land and the general condition of the soil should be as uniform as possible.

When a field or series of plats has been occupied by varietal or cultural tests of such a nature as to seriously increase soil variability, one or more uniform croppings should intervene before it is again used for such tests. It is frequently helpful to arrange the plats at right angles to the direction of previous plats.

For all ordinary field experiments the land should be reasonably level and provision made to prevent undue erosion and to insure proper drainage. When artificial drainage is required, the drains should be located so as to influence all the plats alike. Where irrigation is practiced the applications of water must be regulated and made the same for all plats.

In the case of soil fertility experiments a soil profile to the depth of 3 feet is highly desirable for each series of plats. Before soil treatment experiments are begun, representative samples of the soil and subsoil should be carefully taken for such analyses as may be desired for future reference.

Size and shape of plats.—It is desirable that plats be sufficiently large to carry a representative population of the crop involved, and to provide against undue modifying border effects. The size should be sufficient to minimize the effects of slight discrepancies in soil, stand, harvesting, and threshing. Distinction must necessarily be made between nursery and field plats.

The area and shape of field plats should be such as to enable the operation of standard farm machinery and to reduce to a reasonable minimum errors concerned therewith. There has been a rapidly growing and apparently fully justified tendency to reduce the size of field plats and to enlarge nursery plats from single to multiple rod-rows. Convenient and practical sizes of field plats may range from one-eightieth to one-twentieth acre. Nursery plats containing 3 to 5 rod-rows so spaced as to correspond rather closely with farm practice are suitable for yield determination and for mass observation. In case of great departure from such standard row spacing it becomes advisable to establish the degree of correlation with standard results. It may be desirable to modify the length so as to facilitate the use of factors in transforming yield data.

Relatively long and narrow plats laid out crosswise of the greatest soil variation best overcome the effects of soil heterogeneity. The width should be sufficient to allow for the removal of border rows where this appears desirable, or to render border effects negligible if not removed. Some multiple of 7 feet provides a favorable width for field experiments as it permits the convenient operation of 3½ and 7 foot farm implements. Probably 14 feet may be regarded as a minimun width for crop rotation, fertilizer, and tillage experiments while varietal tests with intertilled crops, such as corn and potatoes, commonly should contain at least 3 or 4 rows. The length may be determined largely by the area desired or by the amount and character of land available.

Interspaces and borders.—In the majority of soils experiments and in many cultural and varietal tests, plat yields may be modified by contiguity to other treatments, crops or interspaces. Border competition among the plants in adjacent unlike plats often raises some yields and lowers others.

Discarding single border rows or their equivalent at harvest is usually a practical solution although for more precision it may be desirable to remove two rows. Interspaces two feet wide may increase the yields of adjacent border rows of small grain plats as much as 100 percent while the second row may be increased 10 percent. The effect of such increased yield may not be serious in case of uniformly treated alleys unless there is a differential response and plats are very narrow. Alleys in varietal tests of closely sown crops, such as small grain and forage, are recommended as a convenience in harvesting and to reduce natural crossing. If the width of these does not exceed 18 inches between marginal drill rows it appears generally satisfactory to harvest the entire plat for yield and to include the additional space in the plat area. Local experience should establish the necessary policy regarding plat borders.

Untreated interspaces of sufficient width to avoid serious soil translocation are recommended for permanent soil fertility, rotation, and tillage experiments. These alleys may either be cropped or left bare.

The universal discarding of border rows in nursery small grain yield tests is recommended.

Replication -- Replication is the most effective means for reducing the effects of soil heterogeneity and other random errors. For the sake of simplicity, the number of replications will be understood to mean the number of plats grown of each variety or treatment. The standard error of an experiment reduces rapidly with increase in replication up to five or six replicates. Any desired degree of precision within practical limits may be ordinarily achieved for any given set of conditions by replication provided all systematic errors have been eliminated.

For field plat tests, from 3 to 6 replications, depending upon the precision desired, are recommended. If average rather than annual results are stressed, the smaller number may suffice. Nursery experiments should ordinarily be replicated 5 to 10 times to assure significant results, with advanced tests approaching the latter number. In soil fertility or crop rotation studies, every crop of the rotation should be represented each year.

Arrangement of varieties or treatments.— The various replications of an experiment should be so arranged that the component plats of each replication tend to fall under like conditions. Arrangement within the various replications may be systematic or random. From the standpoint of statistical analysis, randomization with restrictions to assure against close proximity of replicate plats is preferable. Such arrangement removes the likelihood of correlation between specific treatments or varieties and thereby permits a more accurate determination of the sampling error. The practice of pure randomization without local control is not favored. It would seem that a better distribution of replicate plats, with respect to soil heterogeneity, may be achieved under some circumstances by intelligent placement than by chance location.

Through the use of plats which provide for the elimination of border or plat-competition effects, systematic distribution loses one of its most serious sources of systematic error. This plan facilitates somewhat the mechanical operations and keeping of records.

Where the crop grown on the various field plats differs so much in time of maturity as to necessitate harvesting at different dates, the harvest by farm implements will be facilitated by grouping varieties or treatments that are similar in this respect. The plats could still be randomized within each group.

Further studies concerning the problems of plat arrangement are recommended.

The seed.—All seed used in varietal, cultural, or soils experiments should be of

known vitality and free of trash, impurities, and infection by plant diseases. Except where adaptation of varieties or effects of previous environment is an essential part of an experiment, acclimated seed from constant and known sources is to be preferred. Careful efforts to identify unknown or misnamed varieties introduced into experimental work should be made before publication of results, and new names should not be applied except in cases of necessity. New varieties should be named as soon as it is decided to release them for general use. Records of the history of all seed used should be made and kept on file.

Check plats.—Adequate replication of varieties or treatments removes the necessity of including standard check plats for the purpose of weighting yields, and is recommended wherever possible. One is then assured of actual rather than reconstructed data. Unreplicated data, even with check plat correction, are at best untrustworthy. In all varietal and strain tests it is advisable to include several standard varieties to serve as standards of comparison. When frequent, uniformly treated and equally distributed check plats are employed for weighting results, it is usually most satisfactory to assume that the difference between any two check plats is uniformly progressive.

Cultural operations.—The cultural operations involved in growing and harvesting the crop may become sources of systematic as well as random errors. The importance of uniform cultural treatment throughout an experiment, except in the case of variable treatments under observation, is stressed. Tillage and other uniform operations may be done lengthwise of a series of plats and crosswise of the individual plats. The lateral translocation of soil or fertilizer beyond the plat interspaces of soils experiments should be avoided. Dead furrows and back furrows will not result if a two-way plow is used. The direction of turning the furrow should be reversed at successive plowings. All cultural operations should be completed as far as possible in a single day. Since the manner of fertilizer application may affect yields materially, due consideration should be given to this problem.

Drills and planters should be carefully calibrated and seeding rates should be comparable within an experiment. Since varieties differ in seed size and it is not practical in field experiments with close drilled or broadcasted crops to sow identical numbers of seed per acre, it is fortunate that tests have indicated there may be considerable variation in the stand of such crops without materially affecting the acre-yield. It has also been shown (1) that maximum yields are likely to be secured with a seeding rate slightly higher than that commonly found in practice and (2) that a variation in seeding rate when the latter is near or slightly above the optimum has less effect on the yield than when the seeding rate is less than the optimum. It is therefore suggested that varietal tests with small grains be seeded at a rate at least equal to and preferably somewhat in excess of that commonly encountered in commercial practice. Sufficient approach to uniformity of seeding rate is attained by classifying the varieties as to large, medium, and small seed size and adjusting the drill to sow somewhat more or less by volume according to seed size. With the larger intertilled crops, the planting rate should be somewhat heavier than necessary and the stand thinned to the desired degree at an early seedling stage in such manner as to avoid injury to the remaining plants. In variety tests with such crops in which the varieties differ markedly in vegetative size, it may be advisable to grow certain varieties at two or three different rates to insure fair comparisons. Likewise, due to occasional differential varietal response to time of planting consideration should be given to the question of planting a varietal series at several different dates.

It is considered that stand discrepancies in corn plats need not be taken into consideration in yield determinations where the stand is at least 85 per cent of perfect, provided such discrepancies are rather uniformly distributed. Tests have shown that yields are seldom greatly affected by this much shortage in stand. Where the departure is greater, the plats should be rejected or an effort made to base yield on those hills or parts of plats which are fully surrounded by normal stands. This will seldom be necessary where the planting rate has been increased to permit thinning to the desired stand, and proper precautions have been taken to prevent depredations by rodents and birds.

Interruptions in threshing caused by rain may result in serious errors in the plat weights and test weight of grain. If an experiment cannot be completely threshed in a day or during a period without rain, it will ordinarily be advisable to thresh the various series successively rather than to thresh replicate plats in a group. This will usually insure comparable average exposure for the different varieties. The proper adjustment of the separator should be determined in advance and not changed during the threshing of an experiment. It is advisable to store nursery sheaves under shelter during the interval between harvest and threshing. Where seed is to be saved from varietal plats for future planting, special precautions should be taken to prevent mechanical mixtures

Comparable maturity of crops.—Varieties of forage crops which are normally harvested immature, should reach comparable stages of maturity before being harvested. Likewise the late ripening varieties or treatments in crops normally grown to maturity should be given opportunity to ripen fully just as do the earlier sorts in order to avoid curtailing yield through premature harvest.

Determining yields.—The standard practice is to harvest entire plats except where careful technic requires removal of borders. If this is impracticable, as may be the case with outlying experiments, quadrats or rod-rows, avoiding borders, may be used to represent the yield of a plat. The number of such fractional areas should be made adequate to provide a true sampling of the plat. The number will depend somewhat upon the conditions, but generally should not be less than ten.

All weighings should be made by capable persons and checked wherever possible.

Possible differences in the moisture content of the crop should be taken into consideration in determining yields, and moisture determinations and proper calculations made when necessary to reduce the yields to comparable moisture content. This is of special importance in tests with forage crops and in the case of late-maturing varieties of corn. It is desirable that corn yields be calculated on the basis of shelled corn with comparable moisture content.

In the case of perennial meadows which have become infested with weeds, it is desirable that the percentage of such foreign matter be determined and reported together with the corrected yields.

Duration of tests.—The comparative results from various treatments or varieties are frequently modified or even reversed in different seasons in response to climatic and soil conditions and prevalence of plant diseases and insect or other pests. Continuation of a field experiment over a number of years tends to result in random sampling of such seasonal effects and adds greatly to the significance of the data for application purposes.

RECOMMENDED STANDARDS FOR LYSIMETER EXPERIMENTS

Because of the growing use of lysimeters in replacing field plats at some stations, it has seemed advisable to include in this report standards for the installation and operation of the recommended pit and tank type.

THE PIT

The pit, which is usually of reinforced concrete or blocks, must necessarily be built so that the floor is well below the ground level of the tanks. The top of the pit should not be much higher than the top of the tanks; otherwise it will influence the amount of rain which the tanks will receive. The floor of the pit should slope to an outlet, which may be a small cistern from which the surplus water can be pumped. A trough is advisable for the full length of the pit floor to receive the discarded water.

In the case of a hillside pit, drainage to a lower level obviates the construction of a cistern.

The usual pit will have only the top exposed, but a hillside structure will allow the exposure of one side and the ends as well as the top. The latter type admits of easier access, is more easily lighted and ventilated than the former, but the tanks can be placed on only one side.

A pit 82 feet long, 5½ feet wide, and 6½ feet high is ample for 116 1/10,000-acre tanks, the tanks being placed in a double row along both sides and at one end. This includes a 5-foot allowance at one end for a small table and storage space.

THE TANKS

Materials.—The tanks may be made of any one of a number of materials. Cracks are liable to come in concrete and disintegration of the exposed part takes place in any material that absorbs much moisture. Heavy galvanized iron is the cheapest and most readily workable material. No. 14 iron is advised. Some precautions are necessary in the case of this material. If crops are to be grown, the supply of lime in the soil must be sufficient to neutralize the zinc carbonate or other soluble salts of zinc which may be formed. Otherwise zinc poisoning of the plants may result. The liming required in field practice is sufficient.

A heavy coating of asphaltum is advised both outside the tank before set in place and inside before the soil is placed, but the inside coating will not insure permanently against zinc trouble, which would usually be expected in the course of three to five years.

The size of the tank is governed by the objects in view. If crops are to be grown, a tank 28.27 inches in diameter and which affords 1/10,000 acre of surface soil is highly satisfactory for small grains or other broatcast-sown crops. Larger tanks would be desirable for corn or sorghum. If no crops are to be grown the tanks can be much smaller—1/20,000 acre is a satisfactory size.

The top should be strengthened by an iron strap bradded to the rim. For a 1/10,000-acre tank a strap 1 inch wide and ¼ inch thick is satisfactory.

The depth of the tank is determined by the objects in view. If the study is limited to the changes taking place in the surface layer of soil the tanks should be shallow. For example, under humid conditions, 6 or 8 inches of soil might be desired. Allowing 4 inches of rim above the loose soil, the tank would be 12 inches deep. If the influence of the subsoil is to be studied the depth of tank should be increased accordingly, but only a 1-foot layer of subsoil underlying the 6-inch or other depth of surface soil is advisable in the case of a heavy soil.

It should be noted that common loam and clay loam subsoils retard to a marked extent the outgo. This applies even to nitric nitrogen. Three feet of clay loam subsoil may hold back nitrogen recovery for several years or even vitiate the results altogether. A sandy subsoil, on the other hand, may produce no appreciable effect of this kind, and hence can be several feet deep if desired.

The bottom of the tank.—The bottom of the tank should be constructed so that all free soil water will readily drain off. A cone-shaped bottom with outlet at the center and only a few inches lower than the tank wall is all that is required. A metal strainer is used to prevent stoppage of the outlet by soil. A bottom layer of quartz sand is essential to insure good drainage.

Outlet tubes.—The outlet tubes are usually made of block tin. Tubes with an external diameter of 5/8 inch and an internal diameter of approximately 1/2 inch have proved highly satisfactory. The outlet tube should be of sufficient length to allow a bend to make a water trap, which will limit the free circulation of air. (The trap is similar in shape to that commonly used for kitchen sinks.)

Placement of the tanks.—The tanks should be placed at least 2 feet from the outer wall of the pit. They should be set in the ground so that the soil, concrete, or other level outside the tank will approximately coincide with the soil level on the inside. The outlet tubes should pass through galvanized iron pipes which connect the tank with the pit. This will insure against breakage of the outlet tube and will facilitate tank replacement.

Soil placement.—The soil should be screened through a 1/4-inch-mesh screen and thoroughly mixed prior to placement. It is important that the soil contain only enough moisture to be friable. In order to insure a uniform moisture content at time of weighing into the tanks, the soil should be kept covered during the preliminary operations. A temporary shed may be advisable, especially under conditions of heavy rainfall and when a large amount of soil is to be handled. Covers for the tanks are necessary in order to insure uniform moisture conditions at the outset and also for other control purposes.

The soil should always be placed in the tanks by weight. If large amounts of subsoil are to be used, it is best to put a given weight, representing not more than a 3-inch layer in the settled condition, into each tank in turn. To fill the tanks one at a time invites lack of uniformity in tamping, content of water-free soil, and composition both chemical and physical. The subsoil is compacted uniformly by light tamping after each successive 3-inch layer.

A soil sample should be taken from each tank at the time it is filled and placed immediately in a Mason jar for subsequent moisture and other determinations.

Containers for the leachings.—The containers for the leachings are of galvanized iron, asphalted on the inside, and are provided with removable and close-fitting covers. With a 50-inch rainfall, containers 16 inches in diameter and 18 inches high are of ample size for 1/10,000-acre tanks. When large containers are used a large-sized milk faucet facilitates the drawing off of the water into a tub for weighing and mixing before sampling.

The large containers are set on a shelf or bench, preferably at least 2 feet above the floor of the pit. The smaller containers for 1/20,000-acre tanks need not have faucets and are conveniently set on the floor of the pit.

The outlet tube from the tank passes through a cork set in a thimble near the edge of the cover.

Blank or check tanks.—The rain water should be collected in at least two blank or check tanks of the same size as the soil tanks and should be set up in the series. They need not have more than 6-inch walls, but should be provided with a funnel-shaped bottom like the soil tanks. A flat perforated disc fitting the funnel wall about half-way down will help to prevent the clogging of the outlet.

Preliminary leaching.—After the soil has been placed in the tanks a period of either artificial or preferably natural leaching should be allowed in order to remove excess of nitrates that can be expected to accumulate during the manipula-

tion of the soil from the time of its removal from the field. A record should be kept of the amount of water received during this preliminary period and the amount and composition of the drainage should be determined periodically. The duration of the preliminary leaching is greatly influenced by the nature of the soil and the guidance of analytical data is required.

Fence.—The pit and tanks should be enclosed by a fence which will not permit small animals to gain entrance. The fence should not come near enough to the tanks to influence the rain or snow received by them.

Ground cover.—The ground about the tanks may well be covered with crushed rock or coarse gravel. Weeds and grass may be kept down by chemical treatment.

STATISTICAL ANALYSIS

The principal value of statistical analysis considered in a broad sense is for the purpose of reducing or condensing data in order that they may more readily be comprehended, and for the further purpose of evaluating random errors. The determination of random errors is particularly desirable or necessary (1) when small differences are to be interpreted, and (2) in planning more accurate experiments. Unfortunately, consideration of statistical analysis is frequently deferred until the experiment is completed, when, as a matter of fact the underlying principles should be applied in the planning of experiments. Systematic errors should be avoided and random errors should be reduced to a minimum by careful planning. Moreover, the efficiency and even the justification for using a particular method of calculating probability in a given experiment will depend to a large degree upon the manner in which that experiment has been planned and conducted.

In recent years several new methods of statistical analysis have been developed. Perhaps the most important of these is the "Variance" method by means of which total variance may be resolved into its component parts. Another new contribution which has not been generally recognized among agronomists is M. Ezekiel's graphical method for determining correlation, particularly if the relation is curvilinear. These new developments merit careful consideration.

The application of statistical methods to the analysis of agronomic data involves certain assumptions which are based on definite mathematical relationships. These assumptions are not always justified when applied to agronomic data. It should be recognized that the validity of any conclusions derived by means of statistical treatment depends quite as much upon the assumptions as upon the formulae that are used or the accuracy of the calculations. The modern statistical method may, therefore, properly be regarded as a very useful tool but one that has certain limitations and therefore one that should be used with judgment and discrimination. A broad knowledge and appreciation of statistical analysis will aid in the planning and conduct of effective experiments.

APPLICATION OF RESULTS

After due provision has been made to secure significant data by reducing both systematic and random errors, there still remains the error of application. Results secured under conditions of drouth, low fertility, disease and insect infestation, may not apply where opposite or intermediate conditions prevail, whether seasonal or regional. In like manner there may be a differential varietal response to various dates and rates of planting and other cultural practices. For this reason the modern field experiment anticipates the possibility of such complications and provides for tests under a variety of conditions.

PUBLICATION OF RESULTS

In view of the fact that agronomic literature in common with the literature in other branches of science is becoming more and more voluminous, the following suggestions are made: Extensive reviews of literature should ordinarily be avoided, and only brief citations which have a direct bearing on the data under discussion, included. It is seldom necessary or desirable to present all the detailed data, though enough should be submitted together with sufficient description of the methods employed to permit the reader to draw his own conclusions. Charts or graphs may often be substituted to advantage for extensive tables. Statistical analysis may be used effectively in the reduction and evaluation of data. The advantages of brief yet clear presentation are obvious.

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VARIETAL STANDARDIZATION AND REGISTRATION

Chairman M. A. McCall presented the report of the Committee on Varietal Standardization and Registration which was adopted as follows:

No applications for registration were received during the year. This is the first year since registration was established that this has occurred.

Plans are being considered for the registration of sorghum. These will probably be presented at the next annual meeting.

Attention of the Society is directed to the fact that an official code of nomenclature governing the naming of crop varieties was adopted at the annual meeting in 1917, and is published in the December number of the JOURNAL for that year This code is not being followed by the membership as consistently as is desirable. If changes are desirable, they should be presented to the Society for consideration.

M. A. McCALL, *Chairman*
H. K. Hayes
J. H. PARKER
D. F. JONES
H. B. BROWN
E. F. GAINES
G. H. STRINGFIELD
T. R. STANTON
J. ALLEN CLARK

FERTILIZERS

In the absence of the Chairman, F. E. Bear presented the report of the Committee on Fertilizers which was adopted as follows:

Since the last report of this Committee was made a review of the literature on fertilizer ratios for corn has been completed by one of the members of the Committee In this report the author points out that such experiments have been limited largely to the southern states, and states that, "It would seem highly important for the United States Department of Agriculture and the state experiment stations in the corn belt to carry out coordinated investigations in corn fertilization. Doubtless there is no one ratio universally adapted to all soils but the experiments which have been conducted in the South indicate that for similar systems of farming a ratio or closely related group of ratios may be found which would be quite generally applicable to somewhat closely related soils in a given climatic zone."

A similar report has been prepared for the hay crop and summarized in this Committee's report for 1931, and a report on fertilizers for cotton is being prepared by a member of the Committee. A limited number of the completed reports have been mimeographed for distribution among those interested, and may be obtained by sending a large, addressed, stamped envelope to the chairman of the Committee.

This Committee has during the past year given some thought to the preparation of a standard plan for fertilizer experiments on the fertilizer requirements of crops. It is hoped that this plan may shortly be completed and made available to those interested in this type of work.

A. B. BEAUMONT, *Chairman*
BURT L. HARTWELL
HORACE J. HARPER
F. C. BAUER
FIRMAN E. BEAR

FERTILIZER DISTRIBUTING MACHINERY

R. M. Salter, Chairman, presented the report of the Committee on Fertilizing Distributing Machinery, which upon motion, was adopted as follows:

The Committee on Fertilizer Distributing Machinery has taken an active part in the work of the national joint committee on fertilizer application during the year.

Machine application studies were carried on with corn, cotton, potatoes, sugar beets, lima beans, and snap beans. This work was done at 37 locations in 19 states. A list of the locations of the individual experiments, specifying the cooperation involved in each and the men responsible, may be obtained from the chairman.

It is believed that the fertilizer placement studies with corn, cotton, and potatoes have progressed to a point warranting fairly definite conclusions being drawn. Plans have been made to give publicity to these results for the benefit of both farmers and manufacturers of farm equipment. The problem of the commercial manufacture of suitable machines has already been fairly well solved in the case of corn and potato planters. The feasibility of developing a combined planter and fertilizer distribution for cotton is now receiving attention.

Other problems not dealing directly with fertilizer placement that are now receiving attention or that have been proposed for consideration by the Joint Committee on Fertilizer Application include: (1) Studies of fertilizer movement. (2) particle size in fertilizers, and (3) acid and alkaline mixed fertilizers and the importance of calcium, magnesium, and sulfur in such mixtures.

It is recommended that the committee be continued.

R. M. Salter, *Chairman*
J. R. Fain
H. B. Mann
A. H. Meyer
C. O. Rost
J. J. Skinner
Emil Truog

CORN BORER INVESTIGATION

Chairman L. E. Call presented the report of the Joint Committee on Corn Borer Investigation, which upon motion, was adopted as follows:

Appropriations for corn borer investigations were cut drastically during the current year. Federal appropriations for this research in the Bureau of Entomology were reduced about 40% and those in the Bureau of Agricultural Engineering about 60%. The regular appropriations for the Bureaus of Plant Industry, Animal Industry, Agricultural Economics, and Chemistry and Soils were reduced by approximately the amounts being expended on corn borer research in addition to all other reductions. These are being absorbed as best they can. Funds for corn borer research in the states also were curtailed.

In spite of these drastic reductions, an inspection of the corn borer research under way on August 30, 1933, showed much valuable work in progress. The laboratories of the Bureau of Entomology at Sandusky and Monroe, Ohio, were combined with that at Toledo on July 1, but with no serious lapse in the continuity of important studies that were to be continued. Federal scouting has had to be discontinued because of lack of funds.

The problems being investigated at the Toledo laboratory and farm include the following:

1. Parasite introduction. The rearing and re-colonization of parasites now in their possession is being continued, although on a somewhat reduced scale because of lack of funds. Introduction of new parasites has been curtailed materially.
2. Varietal trials of corn with special reference to tolerance and resistance under varying borer populations, in cooperation with agronomists.
3. Continued research on the development of plowing equipment and the corn combine in cooperation with the agricultural engineers.
4. Insecticide investigations.
5. Surveys of intensity of infestation.

Cooperative investigations between the Ohio Experiment Station and the Division of Cereal Crops and Diseases, U. S. Bureau of Plant Industry on varietal resistance and on breeding corn for resistance and tolerance to the European corn borer are being continued, although on a reduced scale.

Your committee feels that the research is progressing satisfactorily considering the funds available. There is little or no overlapping and the projects which are being continued are those which seem to be most fundamental. We should like to emphasize the importance of continued support for these investigations. The problems being studied necessarily require long-time attack and their solution will provide the best possible information necessary to an intelligent coping with the European corn borer. Further curtailment of this research would prevent the accumulation of much needed new information and render useless much of the work during previous years.

L. E. CALL, *Chairman*

PUBLICATIONS OF THE SOCIETY

C. W. Warburton, Chairman, presented the report of the Committee on Publications of the Society which was referred to the Executive Committee as follows:

The Committee on Publications has given consideration to the situation with reference to the publication of papers presented at the annual meeting and those submitted to the Journal throughout the year. The large number of papers submitted, together with some decrease in the Society's revenues, has resulted in an accumulation of papers on hand nearly sufficient for an annual volume of the present size, exclusive of the 72 scheduled for presentation at this meeting. Prompt publication is desirable, and your Committee has been seeking ways to improve the existing condition which seems likely otherwise to grow worse instead of better.

In order to have the benefit of the experience of similar journals published by other technical agricultural societies, your Committee submitted a questionnaire to the editors of 10 of these journals, 9 of whom sent detailed replies. A tabular summary of the replies is submitted as a part of this report. This summary shows general agreement on a $5 membership fee, a slightly higher rate on foreign subscriptions, the acceptance of advertising, and the furnishing of a reasonable number of cuts without cost to authors. There was less agreement on such items as reprints, exchange lists, and payment of salary to the editor.

Your Committee, after consultation with the Editor of the Journal, submits the following recommendations:

1. A limit of 8 pages on length of papers, with a charge of $4 per page for extra pages. This is less than actual cost to the Society. It is believed that this limitation will result in desirable condensation of papers and increase the opportunity for publication.

2. An increase in the charge to foreign subscribers and members of 50 cents per volume. This is in keeping with the general practice of similar journals and would about cover the cost of foreign postage.

3. Consideration by the Executive Committee of the separate publication in an annual volume of proceedings of all papers presented at the annual meeting, possibly including those papers presented at the annual meeting of the American Soil Survey Association. We suggest that the Executive Committee explore the possible market for such an annual volume to the members of the two societies, to libraries, and elsewhere. This would necessarily be financed outside the present revenues of the American Society of Agronomy.

4. Efforts by the Executive Committee or by a special committee to obtain a grant of funds from one of the numerous scientific foundations or from other sources to assist in financing the Society's publications.

Answers to a questionnaire submitted to editors of nine

	A	B	C	D
Frequency of issue	Quarterly	Monthly	8 issues (except June, July, Aug. & Sept.)	Quarterly
Approximate pages in annual volume	600	950	1,024	400
Average cost per page .	$6.50	$6.50	$1.70	$7.00
Circulation	825	1,250	2,500	1,300
Membership fee . .	$5.00	$5.00	$5.00–$8.00	$3.00
a. Is specific part set aside for subscription to magazine?...	No	Yes	Yes	Yes
b. If so, how much?	——	$4.00	$4.00	$2.00
Do you have higher rate for foreign subscription?	Yes	Yes	Yes	No
If so, how much? ..	$.50	$1.50	$.50	——
Subscription rate to non-members . . .	$5.00	$6.00	$4.00	Not offered
Do you accept advertising?	Yes	Yes	Yes	Yes
a. Approximate amount income from advertising .	$350	$900	$1,200	$400
b. Advertising rate per page.	:$25 00	$15.00	$50.00	$45.00
Do you limit length of articles financed by your journal? . . .	——	No	No	No
a. If so, to how many free pages is author entitled? .	——	——	——	——
b. What is rate per page for extra pages?	——	——	——	——
Do you supply reprints free?	——	No	Pay ½ cost up to 100	Yes
If so, how many? .	50	——	——	100
Do you pay cost of cuts?	Yes	Yes, within limits	Yes	Yes
Do you maintain free exchange list? . . .	Yes	No	Small	Yes
Is editor paid? . ..	——	No	No	No
a. If so, how much? .	——	——	——	——
Does editor act as publisher or are business affairs handled by printer?	Editorial Board	Secy-Treas. of Society	Executive Secretary	Editor, except advertising handled by advertising manager

*Journal of the American Society of Agronomy.

official publications of technical agricultural organizations.

E	F	G	H*	I
Bimonthly	Monthly	Bimonthly	Monthly	Monthly
550 $3.75	576 $28.85	1,300 ——	1,000 $4.97	1800–2000 $3.00 (plus paper and overhead)
1,100 $5.00	14,000 Different classes membership	1,900 $4.00	1,450 $5.00	4,500 $5.00
Yes $2.50	Yes $4.00	Yes $2.50	No ——	Yes $3.00
Yes $.50	Yes $.50	Yes $.50	No ——	Yes $1.00
$5.00 Yes	35c a copy Yes	$3.50 Yes	$5.00 Yes	$4.00 Yes
$1,100	$11,000	----	$677	$6,000
$25.00	$150	$16.00	$30.00	——
No	2,000 to 3,000 words	Yes	No	No
——	——	6	——	——
——	——	$3.00	——	——
Yes 50	No ——	No ——	Yes 25	No ——
Yes	Yes	Yes	$15 limit	Yes, usually
Less than 12 Yes $500	Small Yes ——	Limited Yes $200	No Yes $750	Yes Yes $3,000
Editor, but printer mails bills, collects dues, etc.	Editor, and business dept. of Society	Business Manager	Yes	Yes

C. W. Warburton, *Chairman* W. L. Slate
J. G. Lipman J. D. Luckett, *ex-officio*

LAND UTILIZATION

In the absence of the Chairman, Dr. C. F. Marbut presented a statement from the Committee to the effect that the work thus far had consisted mainly of an analysis of the situation in preparation for a determination of ideal land use. It was suggested that the Committee would not carry on any further activities until the new national set-up on land use had been completed and its activities and functions defined.

SOIL EROSION

During the past year the work at the various soil erosion stations continued to show the marked effectiveness of vegetative treatments in the reduction of surface runoff, the reduction in quantity of soil carried per unit volume of runoff, and the very great reduction in soil erosion.

At the Bethany, Missouri, Station, for example, for 1931 and 1932, the following losses occurred from an 8% slope receiving 70 inches of rain:

Treatment	Soil losses, tons per acre	Water losses % of rainfall
Fallow	192.59	22.10
Corn annually	133.75	25.80
Corn following clover	10.79	9.80
Alfalfa continually	0.39	1.75

Thus, during the 2-year period, the fallow land lost 1.4 times as much soil as did land in corn. The land in corn annually lost 12.5 times as much soil as did that in corn following clover. At the same time, the continuous corn lost 343 times the quantity of soil lost from the alfalfa.

The effect of the vegetative treatments in reducing the quantity of soil carried per unit volume of runoff is evidenced throughout. Where the differences in water losses between corn grown annually and alfalfa annually amount, for example, to 14.8 times, the difference in soil losses is more than 20 times this difference.

Similar results have occurred generally at the stations on many different soil types and including a wide variety of crops.

In addition to the control effected by crop rotation as typified by the above comparison of continuous corn vs. corn following clover, it has been found that the direct application of organic matter has been effective particularly on the highly permeable loessial soils of the Marshall series. Results from the station of the Missouri Valley loessial region illustrate this effect. They cover a 14-month period, Aug. 1, 1932, to Nov. 1, 1933, receiving a total precipitation of 38.4 inches of which 27.4 inches were effective in producing runoff. The soil is an eroded loess having a slope of 8.8%. The results were as follows:

Treatment	Soil losses, tons per acre	Water losses, % of rainfall	Corn yields 1933, bus. per acre*
Check	50.17	21.42	39.79
8 T/A stable manure	17.93	12.30	64.28
16 T/A stable manure	12.33	7.14	84.89
Green sweet clover, low rate†	8.08	9.83	100.00
Green sweet clover, high rate	12.13	8.97	106.73

A corresponding series of treatments which, however, were fallow instead of in corn production showed a higher rate of loss and a less effective control from

*Based upon field weight.

†Low rate has dry matter equal to that of 8 tons per acre of manure.

the treatments, indicating that the crop itself as well as its response to the manure in producing greater development are factors of importance.

The marked effect of fertilizer treatment as it influenced runoff is demonstrated at the Bethany Station when the water losses from an unfertilized clover and timothy plat are compared with similar losses from the same crop but which had been limed and received 180 lbs. per acre of a mixed fertilizer. To illustrate, a single rain of 4.4 inches on Aug. 25 and 26 caused a runoff of 90% on the untreated and 25.7% from the fertilized and limed hay. The hay yields were 1,340 lbs. per acre on the untreated and 3,000 lbs. per acre on the treated area.

The method of growing the crop, particularly as to spacing and direction of row, has been found to have a pronounced effect upon losses of soil and of water. Soil loss from soybeans planted in rows and cultivated was 33.28 tons per acre as compared to 64.3 tons per acre from corn. At the same time the loss from soybeans drilled in 8-inch rows was but 17.5 tons per acre. The water loss from the corn was almost twice as great as it was from the soybeans planted in rows and the loss from the rowed soybeans was twice as great as that from the drilled crop.

On the highly permeable loessial soils having an infiltration capacity in excess of 0.74 inch per hour, a most marked response has been found from contouring corn rows as contrasted with rows running in the same direction as the slope. The rows, slightly ridged at cultivation, have a surface storage capacity when contoured sufficient to retain 1.5 inches of rain This storage capacity, together with the high infiltration capacity, provides a treatment which on purely theoretical grounds should give full protection against 4.5 inches of rain occurring within a period of 4 hours. It has actually been subjected to 4.4 inches occurring within a period of 4 hours and 40 minutes without any runoff whatsoever. These results from the station of the Missouri Valley loess region follow:

Treatment	Soil losses, tons per acre	Water losses, % of rainfall
Corn, 630 ft. slope (listed in direction of slope)	35.33	21.26
Corn, 315 ft. slope (listed in direction of slope)	20.07	21.54
Corn, 157.5 ft slope (listed in direction of slope)	11.18	26.16
Corn, 157.5 ft. slope (listed across slope)	None	None

The average soil moisture content to a depth of 3 feet for the season on the contoured area was 27.54% and on the uncontoured 23.96%, a difference equivalent to 1.49 inches of rain. The corn yields on the contoured area were 55.97 bushels per acre and on the uncontoured 32.93 bushels per acre.

In general, vegetative treatments for the control of erosion have been found to be extremely effective, inexpensive in installation, and very practicable. Many of these treatments, such as crop rotation, the addition of organic matter, cover cropping, etc., may be soundly recommended on grounds other than those for erosion control. However, the very pronounced effects in the control of soil and water losses so frequently found at the soil erosion stations, occurring as they do on many different soil formations and under a diversity of climatic conditions, are of extreme interest and offer much promise in their more general application.

H. H. Bennett, *Chairman*
H. H. Krusekopf W. B. Cobb
A. B. Conner F. L. Duley

STUDENT SECTIONS

E. R. Henson, Chairman, presented the report of the Committee on Student Sections of the Society and announced the winners of the thesis prizes. The report was adopted as follows:

The Committee on Student Section of the American Society of Agronomy reports that sections have been organized in Illinois, Minnesota, Iowa, Kansas, and Oklahoma. The Student Section has approximately 85 members at present. Many additional schools have postponed organization because of the low number of students now enrolled in the field of agronomy.

The committee has sponsored, and the American Society of Agronomy has financed, a student essay contest. This contest was announced this fall and the time available to students for entering was short. The prizes as announced were as follows: First prize, $15.00 and one year's subscription to the Journal of the American Society of Agronomy; second prize, $10.00 and one year's subscription to the Journal of the American Society of Agronomy.

The committee selected the following to receive the prizes: First prize, Virgil Hawk, Iowa State College, for his essay on "Relation of Organic Root Reserves in Red Clover to Winter Killing;" and second prize, Horace Cheney, Iowa State College, for his essay on "Plant Introductions into the United States."

Tentative plans for an annual meeting of the Student Section in Chicago in connection with the crops judging contest have been made for 1934. Essays submitted for the 1934 essay contest may deal either with "Plant Improvement" or with "Soil Improvement."

E. R. HENSON, *Chairman*
F. D. KEIM
H. K. WILSON
W. H. ZAHNLEY
GEO DUNAGAN

Mr Hawk was present and received the check for his award.

PASTURE RESEARCH

H. N. Vinall, Chairman, presented the report of the Committee on Pasture Research, which was adopted as follows:

One of the first things to be done, it seemed, was to ascertain what investigations were now in progress or completed by Agronomists of the State Agricultural Experiment Stations and the U. S. Department of Agriculture. Since many pasture studies are necessarily prosecuted in cooperation with other departments, especially those of Animal Husbandry and Dairy Husbandry, the questionnaire addressed to the Agronomy Departments included both experiments exclusively agronomic in their type and also those of a cooperative nature. Of the entire 48 States replies were received from 42. These have been summarized in more or less detail, but only the totals for each subject will be given here. The summary indicates the number of times or States each problem was under investigation, as follows:

1. Methods of establishing new pastures 16
2. Improvement of old pastures 16
3. Pasture management, including methods of grazing 19
4. Seeds or plant mixtures 21
5. Value of legumes in pastures 8
6. Comparison of species and varieties 28
7. Fertilizers, kinds, value, rate and time of application 32
8. Seasonal growth or variation in production 12
9. Place and value of pasture in farm practice 5

10.	Soil adaptations of various pasture plants	15
11.	Growth habits and life history of pasture plants	7
12.	Chemical composition and nutritive value	13
13.	Mineral content, especially deficiencies in herbage	5
14.	Plant population determinations	14
15.	Palatability studies	10
16.	Effects of frequency, time and height of cutting	10
17.	Weeds and brush, kinds, effect, and eradication	10
18.	Poisonous plants, kinds, effect, and control	3
19.	Survey of pasture resources	7
20.	Determination of organic food reserves	3
21.	Breeding better pasture plants	5
22.	Production of seed and propagation of desirable plants	7
23.	Utilization of surplus pasturage	1
24.	Rodent injuries and control	1
25.	Insect injuries and control	2
26.	Plant diseases and their control	2
27.	Root studies	2
28.	Burning—effect and value	6
29.	Comparison of agronomic and animal husbandry methods	8
30.	Supplemental, temporary, and annual pastures	24
31.	Bloat, occurrence and prevention methods	1
32.	Grazing crops for poultry	2
33.	Use of small animals in pasture research	3

Of course these subjects are broad and some rather important ones, such as carrying capacity or productiveness appear to be omitted. Carrying capacity, however, is almost always discussed in connection with some other subject, such as the method of grazing, value of fertilizers, seasonal production, etc. In other words, production is a measuring stick for the effect of many pasture treatments. The inclusiveness of the subjects is illustrated by seasonal production of pasture plants which usually includes a test of methods to overcome low production periods in various ways, such as the application of fertilizers, the use of supplemental pastures or supplemental feeding either of soiling crops, forage, or concentrates

Some of the most important problems which the committee believes are deserving of more attention concern methods of measuring and expressing the productivity of pastures. Among the methods suggested or already in use are:

1. Carrying capacity expressed as unit-days (cow-days) of grazing per acre. This alone is insufficient but should always be recorded to indicate the rate or intensity of grazing.

2. Recording for the grazing animals gains (or losses) in weight, and milk production and calculating from these data the total digestible nutrients required for the production of these gains or milk which added to the T.D.N. required for the maintenance will give approximately the T.D.N. consumed by the animals. From this is subtracted the T.D.N. in the supplemental feed given the animals and the remainder of the T.D.N. is credited to the pasture. (Careful weighing back of the refused or wasted supplemental feed and determination of the efficiency of animals used would be necessary to make this method accurate.)

3. Determination of the total digestible nutrients obtained by mowing at bi-weekly or monthly intervals plots or quadrats in the pasture. (The greatest objection to this method is that animals in grazing are more or less selective and some of the herbage obtained by mowing would not be included in that obtained by the grazing animals.)

Agronomists need to discover a factor of correlation between methods 2 and 3. The T.D.N. or other feed units indicated by method 2 are in many cases not over 60 per cent of those indicated by mowed plots.

Quality of pasturage is usually determined by associating palatability and nutritive value. Another method is a comparison of the pasture herbage with a

theoretical minimum maintenance ration including the principal minerals. (Prof. Tabor, Georgia. See also Mo. Expt. Sta. Res. Bul. 28.)

More information is also needed on:

1. Effect of the selective grazing, trampling, and the voidings of grazing animals on the growth, persistence, and botanical composition of pasture flora.
2. Soil adaptations of the different pasture plants.
3. The practicability of correcting mineral deficiencies and other nutritive inadequacies by the application of fertilizers as compared with their correction by supplying the grazing animals with mineral mixtures or other supplemental feeds.
4. The value of breeding new strains of grasses and legumes with especial reference to their use as grazing plants.
5. The best methods of utilizing the surplus pasturage in periods of rapid growth.
6. A survey of the climatic and soil conditions and the natural flora of each State in their relation to the productiveness of pastures.

It is also recommended by the Committee that more graduate students be encouraged to engage in studies of fundamental pasture problems. Some of the subjects suggested are:

1. Growth-curve and life history of various species.
2. Genetic studies of important species.
3. Effect of grazing or frequent clipping upon the roots and stolon production.
4. Vitamin content at various stages of maturity.
5. Relation of the growth habits to day length.
6. Monographs (Botanical) of important genera.
7. Botanical surveys of limited areas.
8. Causes of failure of certain species to produce viable seed.
9. Temperature relations of important species.
10. Special morphological characters enabling certain grasses to withstand drought.
11. What percentage of nutrients consumed by the animal are assimilated and what percentage voided on the pasture.
12. Economic surveys of actual farms to determine the relative cost of feed obtained on pastures compared with the cost of harvested feed given in the barn.

Among these No. 11 would necessarily be assigned to a student of animal or dairy husbandry and No. 12 to a student of agricultural economics.

H. N. VINALL, *Chairman* — B. A. BROWN — GEORGE STEWART
A. E. ALDOUS — L. F. GRABER — PAUL TABOR

RESOLUTIONS

In the absence of the chairman, J. D. Luckett presented the report of the Committee on Resolutions, which was adopted as follows:

Following the procedure established with the appointment of a standing committee on Resolutions, your committee has continued, as one of its functions, to take note of the death of members of the Society during the year. At this time we must record the death of Samuel W. Phillips at Zanesville, Ohio, on January 23, 1933. A statement regarding the life and work of Mr. Phillips is made a part of this report.

SAMUEL W. PHILLIPS

1894–1933

Mr. Phillips, a native of Ohio, was born in 1894. He was a graduate of the University of Cincinnati and of Ohio State University, B. S. and M. S. in Agriculture. His work in soil survey in the State of Maryland extended from 1915 to

1917, and he had held appointment as Collaborator in the Bureau of Soils in 1915. In July, 1917, he was appointed Scientist in Soil Survey in the Bureau of Soils, which position he held continuously until October, 1922, with the exception of the period between May, 1918, and September, 1919, when he served during the World War in France. He was in the hottest part of the Battle of Verdun as machine gunner, coming through with an honorable record. He later accepted appointment in charge of Soil Survey for the State of Georgia, and in October, 1923, was reinstated in the Bureau of Soils, Division of Soil Survey. In April, 1929, he was appointed Scientist in Soil Erosion, at which time the Department first took up earnest, comprehensive study of the soil erosion and water conservation problem. Thorough training, broad experience and demonstrated ability were required to carry on research work in this field, and to initiate and carry out collateral lines of investigation. Mr. Phillips' education, training and previous experience particularly fitted him for these duties, which pertained to a decidedly new line of investigations. He was assigned in charge of the Guthrie (Oklahoma) station, the first of the erosion stations to be operated under the Department's new Soil Erosion program, to plan, carry on and direct the work there. Mr. Phillips' publications in the Bureau include a number of soil surveys. He was the first man to take active part in the field side of the national program of soil erosion work, and maintained from the very beginning the heartiest interests in every phase of this. His accomplishments at the Guthrie Station in the Red Plains Region of Oklahoma, are now in progress of publication. Much of the work covered is absolutely original research work. All of it has helped toward the molding of plans for the national program of Soil Erosion and Moisture Conservation. In connection with establishment of the erosion stations he laid the foundation for building other stations for erosion control methods.

His tragic death on January 23, 1933, at the hands of a prowler who entered his home at Zanesville, Ohio, early that morning, was a shock to his associates and friends.—H. H. BENNETT.

THE ECONOMIC SITUATION

Your Committee has during the past year taken cognizance of the adverse effect of financial stringency on many different types of agronomic work. It is unnecessary at this junction to enumerate the causes which have contributed to this unfortunate development. As far as is known to your Committee, agronomic work has suffered neither more nor less than other types of work carried on under the auspices of Land Grant Institutions or the Federal Department of Agriculture. Your Committee feels, therefore, that action by the Society can have no significant effect, for in any case agronomic work is only a part of the work which is suffering from these adverse influences.

REPORT OF THE LAND USE COMMITTEE

AMERICAN SOIL SURVEY ASSOCIATION

WHEREAS, owing to the recovery program, much information concerning the quality of soils, and the classification, appraisal, and utilization of land is being demanded by those who are charged with the refinancing of farm loans, with the adjustment of crop acreages, and with the placing of people upon lands, and

WHEREAS, much of the financial distress in connection with farm land is, to a large extent, due to a misunderstanding of the producing power of the various kinds of soils, and

WHEREAS, groups of individuals attempting to manage lands will encounter the same difficulties as individual operators with the same probable disappointments unless their program is based upon reliable information concerning soil and crop conditions, and

WHEREAS, the present demand for information will continue for many years in the operation of farms which must pay loans, interest, and taxes, and provide subsistence for the operators, and

WHEREAS, accurate knowledge of soil types, their distribution, and possible utilization is fundamental in an effective and successful program of agricultural planning, therefore, be it

Resolved by the American Soil Survey Association, that we present these facts to the President of the United States, The Department of Agriculture, The Department of the Interior, The Agricultural Adjustment Administration, The Federal Agricultural Credit Administration, the Governors of the several states, the Presidents, Deans, and Directors of the Land Grant Colleges and Agricultural Experiment Stations, the executives of various farm loan agencies, the executives of transportation companies, and to others who may be interested, and that we solicit the cooperation and support of the federal and state governments and the several organizations and corporations in securing speedy progress in making detailed soil surveys in the states to serve as a basis for accurate land classification and utilization.

Resolved, that we offer our services as an organization and as individuals in the land classification and utilization program, to which work we can bring the results of years of practical and scientific contact with the soils of the nation.

Resolved, that we request the American Society of Agronomy to concur in this recommendation and that the joint action of the two organizations be communicated to the persons and organizations specified.

Respectfully submitted,
J. GLADDEN HUTTON, *Chairman*
L. L. LEE
L. R. SCHOENMANN
R. S. SMITH

Chicago, Illinois,
November 16, 1933

This report was unanimously adopted by the American Soil Survey Association.
A. M. O'NEAL, *Secretary*.

The above report was unanimously adopted by the American Society of Agronomy.

P. E. BROWN, *Secretary*.

S. B. HASKELL, *Chairman*
E. F. GAINES
F. D. KEIM
G. E. RITCHEY
J. D. LUCKETT, *ex-officio*

OFFICERS' REPORTS

REPORT OF THE EDITOR

J. D. Luckett, editor, presented the following report, which upon motion, was adopted:

It is with a sense of relief that we approach the close of 1933 with the Journal still intact. We feel certain that at no time in the history of the Society has the

outlook for the Journal been so distressing as in the early months of this year. But like many things that seem hopeless, there was a way out, even though the path proved tortuous and the going painfully slow. What with closing banks and falling revenues, the Journal was faced early in the year with a financial stringency that has continued to the present time. We are happy to report, however, that 12 numbers of the Journal have been financed out of 1933 revenues and that we shall enter upon the new year without a deficit.

However, this position, satisfactory as it may be from a financial standpoint, has not been attained without sacrifices in other directions which will make themselves felt in the months to come—notably in the slowing up of the publication schedule. It is this phase of Journal affairs that we wish to discuss in this report.

But first, in order that we might better understand the situation in which we find ourselves, let us compare briefly the 1932 volume of the Journal with the current volume, and the state of our publication affairs at this time last year with that of today. In 1932, we printed 1,046 pages comprising 99 contributed articles, 13 notes, and 18 book reviews, in addition to the usual miscellaneous items and news notes that appear at the end of each number of the Journal. This year we hall print about 850 pages, or nearly 200 pages less than in 1932, and these 850 pages will contain 85 articles, 15 notes, and 9 book reviews But here is the rub We began 1933 with 41 papers on hand, while we now have 69 papers awaiting publication in 1934 We were able to state in last year's report that the 1932 volume would close with the publication of all papers received prior to May 1, 1932 Compared with this, the 1933 volume will close with the publication of all papers received on or before February 3, 1933. This illustrates how rapidly the Journal loses ground with any delay in its publication schedule.

Now we do not cite these figures to discourage you in making contributions to your Journal In many respects we are more fortunate than other technical journals, for all of you know of publications in which delays of a year or more are regarded as a matter of course. Even some of our colleges and experiment stations are having difficulty to keep ahead of the output of the staff, hence it is not surprising that in these times, we should find ourselves dropping behind rather than gaining ground in the matter of getting manuscripts into print.

It is natural that we should ask ourselves, however, whether there is any remedy for the situation. Shall we continue along the same lines as in the past and accept the conditions outlined above as inherent to the situation, or should we seek some expedient that might help us regain lost ground in 1934? These questions were submitted to the Editorial Advisory Committee, to the Committee on Publications, to several members of the Society, and finally to the Executive Committee, and out of the discussion and comments that have ensued a program of action is evolving which is now undergoing careful study by the Executive Committee.

We cannot give you the details of the proposed plan at this time, but they will be published in full in the Journal at an early date. We can, however, give you an outline of the broad features of the proposal from which you may gain some idea of how it will affect you individually as a contributor to the Journal. First of all, we would remind you that in the past the payment of the membership fee to the Society has entitled you to full use of the Journal as a medium of publication, subject only to the usual editorial supervision. There was nothing to prevent you from offering a number of contributions during a single year, and some of you have exercised this privilege. There was no attempt to limit the number of pages that you might use in the Journal, providing you could make out a sufficiently strong

case to the reviewers and to the Editor when your paper came up for consideration. In so-called "normal" times, then, the Journal might be said to have pursued an unusually liberal policy.

In the light of recent experience, however, and in view of the fact that the Society is faced with a continued reduction in memberships and subscriptions so long as federal and state appropriations for agricultural research are so sharply curtailed, we feel that the time has come when we must modify our conception of the responsibility of the Journal to the members of the Society. Our Journal always has been and doubtless will continue to be the official organ of the Society, thus setting it apart somewhat from those journals that serve some specific field of science. In other words, our Journal should continue to open its pages freely to members of this Society and should expedite the publication of their contributions to the fullest possible extent. We believe, however, that the time has come when we must distinguish between the privilege of receiving the Journal in return for the membership fee and the *unrestricted* use of the Journal as a medium of publication. That is, we propose to limit the number of pages available for free publication, with a fixed charge per page beyond this limit. Thus there would be imposed upon the more ambitious contributor something in the nature of a "processing tax" on those pages beyond the established allowance.

It should be understood that this practice, if it is finally approved by the Executive Committee, will never become an important source of revenue to the Society, for two reasons. First, the page allowance contemplated is sufficiently high to care for about two-thirds of the papers normally offered for publication in the Journal. And second, such a policy would undoubtedly tend to discourage the presentation of long papers. The gain, we hope, would be in the speeding up of the publication schedule by crowding a greater number of papers into the limited number of pages the Society can finance, while those who desire to publish longer contributions will bear the added cost. We have yet to hear any objection to the plan in principle, although some of the details of its operation are still under discussion.

But enough about hard times! One or two more matters and this report is done. We have continued to receive invaluable aid from various members of the Society who have been called upon to review manuscripts. This is a thankless task at best but the helpful spirit in which the work is done and the cooperation of contributors in bringing their papers into line with the reviewer's suggestions are important factors in making it possible for the Journal to function as effectively as it does.

During the year we entered into agreements for exchange advertising with several scientific journals in fields related to agronomy, both at home and abroad, as you have doubtless observed from the advertisements appearing in the Journal. It is hoped that this might be a means of attracting new subscribers, particularly in those sections of the world where the Journal is not so well known. And while on the subject of advertising, we are happy to report that there are faint glimmers of a revival of interest in the Journal on the part of advertisers some of which has even manifested itself in the form of new contracts. In this connection, too, we want to cite for distinguished service to the Journal the names of three advertisers who have stuck with us through thick and thin and who are with us for 1934 as well. They are the Urbana Laboratories, the N. V. Potash Company, and Hellige, Inc. We urge your continued support of these and our other advertisers, actual and anticipated.

We are about to conclude twenty-five years of Journal publication and during that time the Journal has grown from a single issue of a hundred pages or so of

"Proceedings" of the annual meeting thru the successive stages of quarterly and bi-monthly publication to eight and nine issues per year, and finally to a monthly publication that ordinarily totals a thousand pages or more annually. So despite the rather gloomy outlook that this report might seem to present, the future of the Journal, we believe, is in no way imperiled. The same spirit of confidence and enthusiasm that has made possible its steady growth in the past will see it through these trying times.

J. D. LUCKETT, *Editor*

REPORT OF THE TREASURER

The treasurer presented the following report which was received and referred to the auditing committee.

I beg to submit herewith the report for the Treasurer for the year November, 1932, to November, 1933.

TOTAL RECEIPTS

Advertising income	$ 448.69	
JOURNALS sold	392.10	
Reprints sold	682.51	
Subscriptions, 1933	1,586.73	
Subscriptions, 1932	15.00	
Subscriptions, 1933, new	269.24	
Subscriptions, 1934	23.00	
Dues, 1933	3,444.50	
Dues, 1932	65.00	
Dues, 1933, new	225.25	
Dues, 1934	20.00	
Total receipts	$7,172.02	
Balance Nov. 1, 1932	459.56	
Total income	$7,631.58	$7,631.58

TOTAL DISBURSEMENTS

Printing the JOURNAL, etc.	$5,796.41	
Salary, business manager and editor	687.50	
Postage (secretary and business manager)	58.00	
Printing, special	139.00	
Express on JOURNALS	40.00	
Mailing clerk	45.88	
Refunds, checks returned, charges, etc.	258.96	
Miscellaneous expenses	233.12	
Total disbursements	$7,258.87	$7,258.87
Balance on hand		$ 372.71
Balance in trust fund in bank		345.33
Balance in cash on hand		$ 27.38

Respectfully submitted,
P. E. BROWN, *Treasurer*

Examined and approved by the Auditing Committee.

F. D. KEIM, *Chairman*
F. L. DULEY.

REPORT OF THE ASSISTANT TREASURER

A. G. McCall presented the report of the Assistant Treasurer, which was received and referred to the Auditing Committee.

The following report was submitted by Dr. A. G. McCall on behalf of the American Society of Agronomy in account with the Executive Committee of the First International Congress of Soil Science November 10, 1932, to November 10, 1933.

Receipts

Sale of *Proceedings* of First International Congress of Soil Science (Washington, 1927)	$ 72.50	
Membership dues and initiation fees for International Society of Soil Science	655.00	
Interest on savings account with Prince Georges Bank and Trust Co., Hyattsville, Md.	71.12	
	$ 798.62	
Balance on hand Nov. 10, 1932 (Savings)	2,016.84	
Balance on hand Nov. 10, 1932 (Checking)	201.55	
		$3,017.01

Expenditures

Membership dues and initiation fees for International Society of Soil Science, transmitted to Dr. Hissink, General Secretary, of the Society	$ 655.00	
Postage for office correspondence	12.50	
Rumford Press (including labor, postage, etc. for distribution of Proceedings)	16.72	
Premium on bond for Dr. A. G. McCall, Treasurer	5.00	
Tax of 2 cents each on checks (bank charge)	.26	
Bank exchange charges on checks	1.05	
	$ 690.53	
Balance on hand as of November 10, 1933 (Savings)	$2,087.96	
Balance on hand as of November 10, 1933 (Checking)	238 52	
		$3,017.01

Submitted by

A. G. McCall,
Executive Secretary, American Organizing Committee

Examined and approved by the Auditing Committee.

F. D. Keim, *Chairman*
F. L. Duley

REPORT OF THE SECRETARY

The report of the Secretary was presented and received as follows:

I beg to submit herewith my report as Secretary for the year 1932–1933—the year of N.R.A.

First of all, I would allay the fears some of you may entertain, that a repetition of past crimes in the way of a report is to be inflicted upon you at this time. In the spirit of N. R. A., may I say that I *N*ever *R*epeat *A*trocities and there are therefore *N*o *R*hymes *A*llowed. I shall merely quite *N*onchalantly *R*elate *A*activties of the Secretary's office for the past year. You may think that *N*othing *R*eally *A*bsorbing in the way of interest ever happens there. It may be so, but regardless of the interest involved, custom or tradition or something (there is nothing in the constitution about it) prescribes that the Secretary make a report at the annual meeting. So here I am, and here you poor, unfortunates are too! But having

partaken of a bounteous repast and listened to the presidential address, the "piece de resistance" of this occasion, and being replete with bodily and mental pabulum, you may retire at any time or sleep here if you wish. But I must stay and present "this here thing" called a report, by courtesy only. Those who have the temerity to stay with me, may now prepare to endure a brief tale of woe, making yourselves as comfortable as possible. For it will be "short if not sweet" as we observe all NRA rules and recognize the fact that *four* hours are long enough for any report. (*N*ecessary *R*eports should be *A*bbreviated). It will also be a sorrowful, tearful story so prepare to weep copiously. (Please do so quietly so as not to disturb the sleepers!) But we will attempt to conclude with a note of cheer, again according to NRA—*N*aturally *R*ejoicing (is) *A*nticipated—which undoubtedly means with a "Hey Nonnie Nonnie and a Hot Cha Cha"!

MEMBERSHIP

The first episode in my pathetic little drama centers around the membership In spite of the most strenuous efforts to prevent a depletion in our ranks (and these included regular notices and appeals—although we hesitated to employ the friendly "kidding" which has proven so efficacious in the past, lest we hurt someone's already bruised spirits and bring down unexpected vials of wrath upon our own heads) 103 members have fallen by the wayside. My books are blotted with tears shed over the sad stories of those who resigned and those who "passed out" by the NPD route, and we sadly ask "where are our wandering boys tonight?" or as we are in Chicago, we may say "Where is Elmer?" It is interesting to note that this decrease is exactly the same as last year (103).

But noble efforts to fill up the ranks with new recruits have met with still more sob stuff—the tune is "Yes, we have no five berries". Our representatives in the states have done "good work and true" but only 46 new members have been added to our rolls and these with 12 reinstatements make an increase of 58. This figure compares depressingly with the 89 increase of last year and leaves us with a net decrease of 45 compared with a decrease of 14 last year.

We are not discouraged, however, as we have kept the membership up over 900—the actual figure November 1 being 904. To do this we have carried over quite a group of NPD's and have simply refused to drop them, hoping eventually to wear down their resistance and collect from them. Some have already cleared up their accounts and are in good standing. So we are hopeful! As for the coming year "why cross that bridge yet?" If all will do their utmost at the various institutions to keep the members in the Society, we will come through the "greatest depression in history" not unscathed, but undiscouraged and undefeated. We shall need the enthusiastic support and backing of all the loyal members of the Society during the coming year to prevent a more serious decrease in our membership. If we are to keep going, to maintain the Journal in its present size and efficiency, we must keep up and build up our list of members and subscriptions. You will all need to do your part! May we depend upon you?

The membership figures are as follows:

Membership, last report		949
New members	46	
Reinstatements	12	
Total increase	58	

Resignations	58		
Dropped for non-payment of dues	47		
Deaths	2		
Total decrease	103	103	
Net decrease		45	45
Membership, November 1, 1933			904

The membership by states and countries is as follows:

Alabama	8	Texas	33
Arizona	13	Utah	12
Arkansas	6	Vermont	3
California	28	Virginia	15
Colorado	17	Washington	12
Connecticut	12	West Virginia	10
Delaware	5	Wisconsin	28
District of Columbia	67	Wyoming	3
Florida	13	Canada	24
Georgia	13	Cuba	2
Idaho	7	Hawaii	13
Illinois	41	Philippine Islands	5
Indiana	24		
Iowa	31	Africa	7
Kansas	29	Argentine	6
Kentucky	9	Australia	2
Louisiana	12	Brazil	3
Maine	6	British West Indies	1
Maryland	14	China	7
Massachusetts	15	Denmark	2
Michigan	18	Egypt	1
Minnesota	22	England	2
Mississippi	7	Finland	1
Missouri	17	Germany	4
Montana	14	Greece	1
Nebraska	19	Honduras	2
Nevada	1	India	4
New Hampshire	1	Italy	1
New Jersey	14	Japan	3
New Mexico	5	Jugoslavia	1
New York	39	Mesopotamia	1
North Carolina	18	Mexico	1
North Dakota	12	Palestine	1
Ohio	35	Peru	2
Oklahoma	17	Poland	1
Oregon	16	Sweden	2
Pennsylvania	19	Switzerland	1
Rhode Island	7	Turkey	1
South Carolina	9	Uruguay	1
South Dakota	10	U. S. S. R. (Russia)	6
Tennessee			

The membership by years is as follows:

1908 Charter	29	1921	39
1908	8	1922	40
1909	3	1923	24
1910	13	1924	34
1911	21	1925	63
1912	12	1926	52
1913	15	1927	52
1914	12	1928	53
1915	18	1929	85
1916	29	1930	68
1917	12	1931	69
1918	10	1932	61
1919	12	1933	45
1920	24	1934	1

The total membership by years is as follows:

1908	121	1917	652	1926	700
1909	129	1918	509	1927	767
1910	176	1919	473	1928	823
1911	236	1920	436	1929	906
1912	295	1921	592	1930	943
1913	349	1922	643*	1931	963
1914	397	1923	561	1932	949
1915	471	1924	577	1933	904
1916	586	1925	646		

SUBSCRIPTIONS

Our subscription list has also decreased slightly but not as much as last year. Thus far, payments from subscriptions have been coming in very well. The subscription figures for the year are as follows:

Subscriptions, last report		546
New subscriptions	77	
Subscriptions dropped	93	
Net loss	16	16
Subscriptions, November 1, 1933		530

Libraries are having difficulty in keeping up all their subscriptions and this fact accounts for our decreased total, but it is encouraging that we have entered so many new subscriptions. We hope to keep our subscription list from falling off any further.

TREASURER'S REPORT

The Treasurer's report has been made to you briefly and by summary only, but as "side-kick" of the Treasurer and being quite familiar with the whole story, the Secretary will give you the "inside dope." It's another sad, sad tale. Again be prepared to weep with us and for us!

The report was made up in two parts, the first—A. D. to B. C. meaning from the annual dinner in 1932 until the bank closed on February 2, 1933; the second B. O. to A. M. meaning from the time the bank opened until this annual meeting. And "thereby hangs the sad tale." Yes, the bank in which the Society account was carried, closed most unexpectedly and just when we had thought that our banks would pull through. This happened before the national bank holiday and after the holiday the bank opened and operated under state control until they secured waivers from sufficient depositors to permit them to open "on their own." This required that fifty percent of all deposits be placed in a trust fund as segregated assets. The remaining fifty percent went into depositors certificates which were to be paid off as rapidly as possible.

Fortunately, the Treasurer was ill with a second attack of the "flu," for several weeks prior to the closing of the bank, and hence considerable funds were not deposited and were saved from being tied up. It's the only fortunate thing I can think of in connection with a flu attack! As the Treasurer's account showed $345.33, or 50% of our deposits, were tied up. Of the other 50%, 15%, or $51.80, was paid off by the bank in September and the remaining $293.53 was advanced to the account and we are out from under all but the trust certificate. That's that!

But the "plot thickened" when the bank holiday came along. And after it was over, checks came back by the score. In one month over 40 checks were returned.

It took a lot of correspondence and caused much difficulty to get the situation straightened out. We hope never to have to go through so much confusion, uncertainty, and worry again, certainly not on top of two flu—or near pneumonia seizures! But as a whole, we have pulled out of a bad situation much better than we had any reason to expect and it looks now as if we would not lose anything in "the last round-up" which "we are heading for." So let us all join in singing "happy days are here again" without referring at all to 3.2% or the repeal of prohibition.

JOURNAL

In spite of all the difficulties which have confronted us, Professor Luckett has kept the Journal going for the entire year. We discussed very seriously "what to do", when, early in the year, it was apparent that we were in financial difficulties. We finally agreed to keep the size of the issues down and publish monthly, just as long as we could see our way through. It was a source of considerable worry, for there was the well-known "wolf" sitting just outside our door all the time and I shuddered every time I opened my mail lest we were about to be more than financially embarrassed. But we managed to print and *pay* for 12 issues of the Journal with only some little delay in paying the printer. I do not know yet just how it was done, but we got by and now we can say "who's afraid of the big bad wolf?" We can go out now and pat him on the head—in fact he's been around so long now that he seems a part of the establishment.

SALE OF JOURNALS AND ABSTRACTS

We have sold quite a number of copies of the abstracts printed for the last annual meeting and largely left on our hands and rather a considerable sale of Journals has been made. It is unfortunate that many issues of recent volumes are out of print and full sets cannot be supplied. I had one order from a foreign country for a complete set of the back issues with a check enclosed to cover the total cost at five dollars per volume. How I hated to send back a large part of that money because so many issues were out of print and the prices of the earlier issues were not as high as the buyer had figured. But I couldn't figure any way to avoid the refund. It does help to sell back copies and the income from this source has been especially welcome this year. It is "pure velvet."

MEETINGS

The Society joined with Section O (Agriculture) of the American Association for the Advancement of Science and several of the Botanical Societies and also with the Economics societies in a series of programs at the Summer meeting of the Association in Chicago in June. A number of distinguished visiting scientists from abroad served as centers for some very interesting programs and all attending reported very fine meetings. It may be mentioned that it was not at this meeting that "Elmer was lost."

The Northeastern Section of the Society has arranged a program to be given jointly with Section O in Boston on December 28. The subject is "Field and Microchemical Methods for Determining Soil Deficiencies," and the program has been arranged by Professors T. E. Odland, M. F. Morgan and M. H. Cubbon. All who can arrange to attend are assured of an interesting and profitable time. The members of the Northeastern Section say "Whyncha come up some time?"

The program for the annual meeting arranged by President McCall, Dr. Jenkins, and Dr. Bradfield, in cooperation with President M. F. Morgan of the

Soil Survey Association, was finally printed and distributed to the entire membership, after several misunderstandings were straightened out and other difficulties were overcome (we almost had one paper on both a crops and a soils program). We are surely indebted to these officers for the wonderful programs which have been set up. Incidentally, the little billet doux inserted unobtrusively in the programs attracted some attention and quite a little in the way of the wherewithal to pay running expenses has already come in. Sort of a painless extraction method! I cannot tell a lie, it does *not* hurt me worse than it hurts you

APPOINTMENTS

The general committees of the Society were continued and appointments made by President McCall. A new committee on Pasture Research was established with Prof H. N. Vinall as chairman

Prof M. F. Morgan of Connecticut was appointed as our representative on the Council of the American Association for the Advancement of Science to replace Prof. J J Skinner, who did not qualify.

Dr. K F. Kellerman of the Bureau of Plant Industry was appointed the representative of the Society on the Institute for Research in Tropical America. We had had no representative in this Institute since the death of Dr. R. A. Oakley.

Dr E F. Gaines of Washington and Dr. J G. Dickson of Wisconsin were appointed to represent the Society at the Fifth Pacific Science Congress held at Vancouver in June. Dr. Gaines attended the meetings and reported a very fine time.

Vice-President Throckmorton and the Secretary have recently been invited to become members of a Radio Conservation Council sponsored by the National Broadcasting Company to arrange for a series of conservation programs during the coming year.

MISCELLANEOUS

And now we come to that "Mother Hubbard" of all reports—Miscellaneous. But it is not so closely scrutinized anywhere else as in the Treasurer's report so we need not worry.

There may be a depression all over the country—indeed I have it on the very best authority that something on that order has been noticed by a few people, at least—but the correspondence of our office during the year would not even suggest such a thing. It does seem that there is even a greater mass of material coming to the Society than ever before. A recent suggestion to the "tired business man" that he can save energy by not opening second class mail, would not help much in this case, as most of the material comes first class. But we long ago gave up the courteous but expensive habit of acknowledging all communications.

We have received the usual mass of invitations to hold our conventions in cities such as Indianapolis, Montreal, New York, Philadelphia, Detroit, Albany, Cleveland, Atlantic City, Nashville, Tenn., Del Monte, Calif., Pinehurst, N. Car., French Lick Springs, Ind., White Sulfur Springs, W. Va., Buck Hill Falls, Pa. and many others. If any of you would like to meet in any of these cities, perhaps we can induce the Land Grant Association to go to them. Their advertising is of the "California type" and it seems as if we were missing the "time of our young lives" by not going to them. They all seem to think that theirs is the best city on the globe. What enthusiasm, what glowing statements of facilities, advantages, entertainment, etc.! What an intense desire to provide us with everything we

need or can possibly wish! They don't say at what price! But the loyalty of Americans to their own cities and towns is a wonderful thing. Recall the comment made after a Californian had made a most enthusiastic and not entirely accurate speech about his native or adopted state—"So you won't talk, huh!"

And we have also been offered a "Sea Going Convention to Bermuda." Now that's something, but one of the chief talking points in favor of such conventions will soon be removed and it will, strangely enough, be just as wet on land as on the sea!

Scores of hotels offer us their facilities—I have cards permitting of the use of some hotel gymnasiums—if any of you feel the need of exercise. Badge companies, printers, reporters, commercial photographers, bus companies, express agencies, travel bureaus of oil companies, railroads and even airplane companies offer us their services and facilities not *once* but many times. Many ask for lists of members which occasionally we supply, but having consideration for you, we don't do it often.

Entertainment is offered in Chicago of a wide variety. We could "jazz up" this annual dinner very materially by accepting the suggestions of some of these commercial professional entertainers. What, no orchestra! What, no singers! What, no comedians! What, no dancers! What, no entertainment! For gosh sakes, why have a banquet? That's the usual reaction! A convention in Chicago without even a "fan" dancer! Incredible!

Invitations and guest tickets for night clubs and shows have come to us. One cafe called "The Stables Barnyard" seems particularly appropriate. Dancing from 8:30 until dawn. Thnk of it, free drinks—the waiters sing and the cooks dance! There's a novel place! Another most popular, exclusive and intimate rendezvous along the Gold Coast offers dinners, entertainment, a newly installed bar, where America's finest beverages are served at drastically reduced prices is open from 5:30 until the "wee, small hours of the morning." I have a membership card I will be glad to pass along! These are merely samples of the advertising received. I except all those members of the Society who are here at the annual meeting but have "cut" this dinner may be found at some one or other of these "night life" places. Perhaps we should call the roll tomorrow morning and have a report from those absent tonight.

And then there has been the constant regular, legitimate correspondence, a never ending mass which requires attention. I wish I had kept count of the letters written, the mail received and the outgoing pieces of mail. But perhaps it is just as well not to know. At least it has all been handled and reasonably promptly.

I am glad to do what I can to keep our whole machine of the Society operating "on all eight." But we must have the "oil" supplied by members in dues and by subscriptions if the Journal is to be continued on its present efficient basis. Professor Luckett is more than doing his part. But we must have sufficient funds on which to operate. It's not "keeping up with Lizzie" it's a matter of "supporting the Journal in the style to which we have become accustomed." Let everyone do his part and the future of the Journal and of the Society is secure!

P. E. Brown, *Secretary*

FELLOWS

The Fellows-elect were announced by President M. A. McCall (pages 000) and presented with diplomas. Those receiving this honor were Professor R. I. Throckmorton, Dr. R. J. Garber, and Professor A. R. Whitson.

ANNUAL DINNER

At 6:30 p.m. on November 16, the annual dinner of the Society was held at the Stevens Hotel at which time Dr. M. A. McCall delivered the address of the retiring president (pages 000 to 000).

Chairman M. T. Jenkins of the Crops Section moved the appointment of a special committee to investigate the subject of the standardization of statistical notation as applied to agronomy. The motion was carried.

The Nominating Committee report was made by President M. A. McCall and the following officers were declared elected for the year 1933–34: H. K. Hayes, Vice-President; R. M. Salter, Wooster, Ohio, and J. G. Dickson, Madison, Wisc., representatives of the Society on the Council of the A.A.A.S. R. I. Throckmorton, Manhattan, Kansas, automatically succeeded to the presidency of the Society.

P. E. Brown, *Secretary*

OFFICERS OF THE SOCIETY FOR 1934

R. I. Throckmorton, Manhattan, Kan., *President*

H. K. Hayes, St. Paul, Minn., *Vice-President*

H. L. Westover, Washington, D. C., *Chairman Crops Section*

C. F. Shaw, Berkeley, Calif., *Chairman Soils Section*

J. D. Luckett, Geneva, New York, *Editor*

P. E. Brown, Ames, Iowa, *Secretary-Treasurer*

R. M. Salter, Wooster, Ohio

J. G. Dickson, Madison, Wis.
Representatives of the Society on the Council of the A.A.A.S.

AGRONOMIC AFFAIRS

REPORT OF THE MEETINGS OF COMMISSIONS II, III, AND IV OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE HELD IN COPENHAGEN DENMARK, AUGUST 7 TO 13, 1933

The following report has been prepared by Dr. S. A. Waksman and Dr. Richard Bradfield on behalf of the American delegation to the meetings of Commissions II, III, and IV of the International Society of Soil Science.

In preparation for the Third International Congress of Soil Science, which is to take place in Cambridge, England, during the summer of 1935, Commissions II, III, and IV of the International Society of Soil Science held their preliminary meetings last summer in Copenhagen. These meetings were followed by a two-day excursion to Jutland, for the examination of heath soils and their utilization. These meetings were attended by over 100 scientists, representing 20 different countries. There were only three delegates from the United States, namely, Professor M. F. Miller from Missouri, Professor Richard Bradfield from Ohio, and Professor S. A. Waksman from New Jersey. The interests of the three American delegates were divided among the three Commissions.

The general Commission meetings were preceded by a meeting of the Executive Committee of the Society in which plans for the Third Congress were discussed. Since Sir John Russell, President of the Congress, could not be present in Copenhagen, Dr. Crowther of the Rothamsted Experiment Station presented a report of the British Executive Committee. It is planned that the actual meetings of the Congress should last about a week. These will be followed by an excursion of about three weeks duration to Scotland, England, and Wales. The scientific meetings will be divided partly into plenary sessions and partly into Commission meetings. There will be six plenary sessions, each Commission preparing the program for one plenary session and presenting a subject which is of outstanding importance in the activities of the particular Commission. The various Commissions will then have three to six individual sessions for the presentation of papers of particular interest to the various Commissions.

The subject of each plenary session will be decided upon by the corresponding Commission. The papers presented at the plenary session will be by invitation and will be followed at the end of the session by a brief discussion. However, the papers presented at the Commission meetings can be both by invitation and by presentation by the author. Special efforts will be made by the British Organizing Committee to reduce the cost to the participants, both during the Congress and the excursion, to a minimum.

The Commission meetings began on Monday, August 7, and lasted until Friday. The Second Commission met on August 7, 8, and 9 and the Third and Fourth Commissions began their meetings on August 9. The programs of the three Commissions were so conveniently arranged that there was no conflict between the different

sessions, so that the delegates could attend all of the sessions if they so wished. Towards the end of the meetings several special committees which were appointed during the first sessions of the Second Commission, especially the Committees on Methods of Determination of Soil Reaction and Methods for Measuring the Base Exchange Capacity of the Soil, attracted a number of delegates who could not thus be present at the meetings of the other two Commissions.

The Soil Reaction Committee decided to make a cooperative study of the use of the glass electrode for soil reaction measurements. Prof. C. La Rotonda of Italy, Dr. Jac van der Spek of Holland, and Professor Richard Bradfield of Ohio were appointed as additional members of this committee.

No decision was made regarding an official definition of the concept "base saturation capacity." It was recommended that the methods proposed be studied further and that the subject be considered again at Cambridge in 1935

The Proceedings of the Second Commission have been published as Volume A of the Copenhagen Conference. This volume contains the papers which were presented before this Commission. It will be followed later by Volume B, which will contain certain additional papers which came in later but which were presented before the Conference, and a discussion of the papers presented. Commission III has not published its Proceedings and does not intend to do so except for a very brief summary, which will probably be published in the Proceedings of the International Society. The same is true of Commission IV. Some of the committees, as that on soil reaction and that on the determination of nutrients in soil, presented quite elaborate programs of their own as a part of the Proceedings of the Second Commission. The Russian delegates to the Conference brought with them proof of the papers presented by the Russians before the three Commissions. It is the anticipation of the Russian soil scientists to publish these in a special volume which will no doubt be sent to all the members of the Society.

The papers presented before the Second Commission were divided into five distinct subjects, as indicated in the following list:

Subject 1.

K. Bamberg: Die Laboratoriumsmethoden zur Bestimmung der Düngerbedürftigkeit der Böden müssen den Bodeneigenschaften bzw. Bodentypen angepasst werden.

J. di Gleria, A. Schönfeld, L. v. Telegdy-Kovats und Fr. Zucker: Ergebnisse vergleichender, in den Jahren 1929–1932 mit verschiedenen Methoden durchgeführten Untersuchungen an ungarischen Böden.

P. L. Hibbard: A comparison and evaluation of several methods for estimation of plant available phosphorus in soils, with special reference to semi-arid soils.

D. J. Hissink und C. Spithost: Die Bestimmung der Phosphorsäurebedürftigkeit der Böden mit Hilfe der Zitronensäure—(*Lemmermann*), Keimpflanzen—(*Neubauer*) und Salpetersäuremethode (*von 'Sigmond*).

D. R. Hoagland: Methods for determining availability of potassium with special reference to semi-arid soils.
K. Krumins: Über die Anwendung des Zinnstabes bei der Phosphometermethode.
H. Neubauer: Eignen sich Feldversuche oder Laboratoriumsmethoden besser zur Bestimmung der Düngerbedürftigkeit der Böden?
A. A. J. von 'Sigmond: Über die Auswirkung des Bodentypus auf den Nährstoffuzstand des Bodens.

Subject 2.

S. A. Arany: Bemerkungen zur Bestimmung der austauschbaren Basen der Karbonatböden.
R. Bradfield and W. B. Allison: Criteria of base saturation in soils.
J. di Gleria und L. Kotzmann: Die Ungesättigtheit der Böden vom Standpunkte der Kolloidlehre aus betrachtet.
A. A. J. von 'Sigmond: Beitrag zur Begriffsbestimmung des Sattigungszustandes des Bodens.
A. M. Smith: The estimation of the "lime requirement" of the soil.

Subject 3.

J. A. Naftel, C. J. Schollenberger and R. Bradfield: A study of the methods for measuring soil reaction.
A. M. Smith: The variation in soil acidity.

Subject 4.

L. Kotzmann: Die wünschenswerte Richtung der bodenkundlichen Humusforschungen.
C. Spithost: Die Bestimmung der gesamten organischen Substanz des Bodens.
S. A. Waksman: The origin and nature of humus.

Subject 5.

A. I. Achromeiko: Zum Studium der Frage über die Einwirkung von Kalk, Stalldünger und Wurzelsystem der Pflanzen auf die physisch-chemischen Eigenschaften des Bodens.
H. Harrassowitz: Die Abgrenzung allitscher Böden.
E. I. Ratner: Der Einfluss steigender Mengen von austauschfähigem Natrium auf die physischen Eigenschaften des Bodens und den Pflanzenwachstum.
A. Reifenberg: Die Zusammensetzung der Kolloidfraktion des Bodens als Grundlage einer Bodenklassifikation.
D. Wolf und R. Kächele: Über das chemische Verhalten der Tonsubstanz im Ackerboden.

In addition to these meetings, there was also held a special meeting of the Alkali Sub-Commission. Two papers were presented before this Sub-Commission:

D. J. Hissink: Die Salztönboden und die Alkalitonböden in den Niederlanden.

L. von Kreybig: Über die zeitweisen Änderungen der pH-Werte in gewissen Alkaliböden und deren Einfluss auf das Pflanzenwachstum.

The Third Commission held three sessions, the first of which was a joint session with the Second Commission under Subject 4. The program of this Commission was as follows:

Session I.

Microbiological Analysis of Soils as an Index of Soil Fertility

Prof. S. Tovborg-Jensen, Denmark. The contribution of Professor Harald Christensen to the subject of microbiological analysis of soils.

Dr. A. Steven-Corbet, England. The carbon dioxide method of evaluating soil microbiological activity.

Prof. H. Niklas, Germany. Application of microbiological soil investigations to soil fertility problems (Nutzbarmachung der mikrobiologischen Bodenuntersuchung fur die Praxis).

Prof. H. Niklas, Germany. Determination of potash and phosphorus requirements of soil by means of the Aspergillus method of Niklas, Poschenrieder, and Trischler.

Dr. E. J. Petersen, Lyngby. Untersuchungen uber mikrobiologische Methoden für Bestimmung der Phosphorsaure bedürftigkeit des Bodens.

Prof. E. E. Uspensky, U. S. S. R. Estimation of soil fertility by microbiological methods.

Session II.

The Rôle of Microorganisms in the Decomposition of Organic Matter in Soils and the Formation of Humus

Dr. A. Dunez, France. Sur le rôle des thermophiles dans l'humification des pailles par fermentation chaude.

Prof. S. A Waksman, U. S. A The origin and nature of humus.

Mme. Y. Ziemiecka, Poland. Decomposition of pentosans by bacteria.

Prof. I. W. Tjurin, U. S. S. R. Contribution to the problem of studying soil organic matter in respect to its biochemical importance.

Prof. C. H. Bornebusch, Denmark. Influence of thinning on the biological factors of forest soil.

Dr. O. Flieg, Ludwigshafen. Dreijärige Strohdüngungsversuche.

Dr. F. Schaeffer, Halle, Germany. The rôle of lignin in the formation of soil humus.

Session III.

The Present Status of the Problem of Nitrogen-Fixation by Leguminous Plants and the Problem of Soil Inoculation

Dr. H. G. Thornton, England. The influence of the legume host-plant upon the formation and activity of nodules.

Dr. E. B. Fred and associates, U. S. A. The effect of pCO_2 on nodule formation by clover in presence of combined nitrogen.

Prof. Henri Burgevin, France. Influence de l'inoculation sur la nutrition azotee des legumineuses dans la pratique agricole.

Prof. K. Aso, Japan. The present status of soil inoculation in Japan.

Among the special discussions brought up before the meetings of the three Commissions, the following two deserve careful consideration: 1, The value of the results obtained from the testing of soil by the plant culture methods, by chemical methods, and by biological methods; and 2, the official adoption by the Third Commission of biological methods for the determination of the presence in the soil of the important plant nutrient elements in an available form.

Professor Mitscherlich suggested that he would be willing to carry out tests by his well-known plant culture method for the abundance of available nutrients on any soil that might be sent to him. It was further suggested that the same soil should also be tested by chemical and possibly by biological methods. Professor Sigmond proposed that a committee be appointed, consisting of representatives from the three Commissions, which should supervise these tests. In accordance with a resolution adopted by the three Commissions, any member of the Society who is interested in having a special soil analyzed for the available nutrients or need of nutrients can send a portion of that soil to Professor Mitscherlich, who will have it tested by the plant method, and another portion to Professor Sigmond, who will have it tested by certain chemical methods. As to the microbiological tests, the Third Commission felt that it could not commit itself as yet to any definite recommendations in this connection. However, Dr. Thornton of the Rothamsted Station was appointed to represent this Commission in the joint committee. He may be able to correspond with those microbiologists who are interested in making such tests and send the particular soil to them, so as to be able to compare the results thus obtained with the results of the plant and chemical tests.

Dr. Niklas proposed that the *Aspergillus niger* method for the determination of potash and phosphoric acid in the soil be adopted by the Third Commission as an Official Method for the determination of these nutrients in an available form in the soil. After considerable discussion, the Third Commission expressed itself as not yet prepared to recommend any such official action. It was felt that this method is still in the experimental stage and has altogether too many limitations in order to justify its adoption as an official method.

A BIBLIOGRAPHY ON STATISTICAL METHODS

An attempt to collect all of the works dealing with statistical methods relating chiefly to the application of the analysis of variance has culminated in a mimeographed bibliography prepared by Dr. Ch. Zinzadze in the Statistical Department of the Rothamsted Experimental Station, Harpenden, Herts, England. The bibliography is prefaced by a statement on Dr. Zinzadze's work by Professor F. Yates, head of the Statistical Department at Rothamsted.

According to the author, the bibliography is designed to introduce the beginner to the study of the analysis of variance and to supply the advanced research worker with the principal publications up to the end of 1933. The list of references is classified as follows: 1, Field Experiments, including general, methods of estimating the yield of missing plats, principles of orthogonality and confounding in

replicated experiments, and work with tea, cotton, etc.; 2, Horticulture; 3, Plant Physiology; 4, Soil Science and Soil Bacteriology; 5, Meteorology; 6, Fisheries; and finally, books and general works on statistics.

MINUTES OF 1933 BUSINESS MEETING OF THE CROPS SECTION

M. T. Jenkins, Chairman, called the Crops Section to order for a business meeting at 5 p.m., Thursday, November 16, in the Stevens Hotel, Chicago, Ill. The report of the committee on Organization of the Crops Section was read by the chairman from the minutes for the annual meeting of 1932. For the organization of Crops Section, see this Journal, Vol. 24, page 1011.

The nominating committee, composed of H. K. Wilson, Chairman, S. C. Salmon, and J. B. Park, proposed the following program committee for the annual meeting of 1934: H. L. Westover, Chairman, R. G. Wiggans, and John Parker. A motion that the proposal of the committee be accepted was made by H. K. Wilson, seconded by G. H. Cutler, and was passed unanimously by the members of the Crops Section.

W. P. Carroll of the U. S. Dept. of Agriculture called to the attention of the members of the Section, the proposed revisions in the federal grain standards and urged that these proposed revisions be given critical examination and that any suggestions be reported to the Bureau of Grain Standards, U. S. Dept. of Agriculture.

The meeting adjourned.

LeRoy Powers, *Secretary*

NEW POLICIES GOVERNING THE JOURNAL

Confronted with mounting demands for space in the Journal and with a sharp falling off in revenues, the Executive Committee at its meeting in Chicago in November approved certain changes in the management of the Journal looking to the most efficient and economical utilization of the Society's resources. The Journal will continue to accept contributions from members of the Society only and to submit them to review, as in the past. In addition, certain limitations have been set on the Society's responsibility to the contributor.

FREE PUBLICATION RESTRICTED

As a first step toward a speeding up of the publication schedule, hereafter all contributed articles will be limited to 8 pages of free publication. All pages beyond the first 8 will be charged for at the rate of $4.00 per page. In passing on contributions, the Editor will indicate the probable length in cases where the paper will exceed the 8-page limitation, and the contributor will be asked to guarantee payment for the additional pages.

FREE REPRINTS DISCONTINUED

For the past several years, the Journal has been supplying a limited number of free reprints. Of necessity, the number of free reprints has been small, but even at that the expense to the Society is an important item in the year's business. Beginning with the January, 1934, number, therefore, all free reprints will be discon-

tinued, a nominal charge being made for all reprints ordered by the author. A rate card on reprints and an order blank will be supplied at the time galley proof is sent out.

ALLOWANCE ON ILLUSTRATIONS REDUCED

The making of half-tones and zinc etchings for illustrations in the Journal has constituted a heavy drain on the Society's funds. Sometime ago the Society's liability in this direction was limited to $15, and this amount has now been reduced to $10 per paper. The Editor will supply information on costs of illustrations whenever desired.

NEWS ITEMS

FLOYD L. WINTER, formerly agronomist for the Hoopeston Canning Company of Hoopeston, Ill., is now Geneticist for the Associated Seed Growers, Inc., of New Haven, Conn. Mr. Winter will have charge of the Pacific Coast department of breeding at Milpitas, Calif.

FREDERICK D. RICHEY, now in charge of corn investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, has been named Associate Chief of the Bureau, effective January 1. Mr. Richey will aid in the general administration of the Bureau and will give special attention to the Bureau's research activities.

Dr. KARL F. KELLERMAN, formerly Associate Chief of the Bureau of Plant Industry, U. S Dept. of Agriculture, has been named head of the Division of Plant Disease Eradication and Control in the Bureau of Entomology and will have under his direction all of the activities aimed at the control and eradication of the phony peach disease, blister rust, barberry, citrus canker, and Dutch elm disease.

Dr. FRANK T. SHUTT has retired from his position as Dominion Chemist and Assistant Director of Dominion Experimental Farms of the Canadian Department of Agriculture after more than 45 years of service to Canadian and world agriculture.

Dr. C. A. BROWNE of the Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, can supply information about the Third Technical and Chemical International Congress of Agricultural Industries which is to be held in Paris the week of March 26, 1934. Those who attend this Congress will also have an opportunity to participate in the Ninth International Congress of Pure and Applied Chemistry in Madrid which begins on April 5.

GILBERT LEA, who has a fellowship supported by the N. V. Potash Export My., received the Master of Science degree in soils last June from the Vermont Agricultural College. Mr. Lea returned October 1 to complete further studies on potash. After the first semester he intends to work toward a Doctor's degree at the University of Wisconsin.

H. G. M. JACOBSON, Assistant Agronomist, Connecticut Agricultural Experiment Station, New Haven, Conn., is on leave of absence until April, 1934, to pursue graduate studies in plant physiology at the University of Chicago.

ROSCOE WILFRED THATCHER

Dr. R. W. Thatcher, Research Professor of Agricultural Chemistry at the Massachusetts Agricultural Experiment Station, died in his laboratory on the morning of December 6. Dr. Thatcher was a charter member of the American Society of Agronomy, President of the Society in 1912, a Fellow of the Society, a frequent contributor to the JOURNAL and to the programs of the annual meetings, a member of many important committees, and Editor of the JOURNAL from 1921 to 1928. At the time of his death he was Chairman of the Editorial Advisory Committee and during the past few months had given considerable thought to ways and means of meeting the difficulties that have confronted the JOURNAL during the past two years.

Director F. J. Sievers of the Massachusetts Experiment Station, at the request of the Editor, has prepared the following statement for the JOURNAL.

"The sudden death of Dr. R. W. Thatcher would have caused more of a shock only if it had not been known to his many friends and admirers that, because of poor health, he felt forced more than a year ago to retire from his position as President of Massachusetts State College to a position of Research Professor of Agricultural Chemistry in the Experiment Station. He died in his office on the morning of December 6, while at work on his project covering a phase of plant nutrition in which he had developed a pronounced interest and to which he was giving very effective leadership. His enthusiasm for opportunities in this field, after he was no longer burdened by the former many administrative responsibilities, was not only inspiring to his associates but convincing of the many years of real constructive service that he might still have been able to render.

"It would be futile to enumerate his many accomplishments and to give a record of his experience. Both of these are not only well known to his many friends, but they are also available in *Who's Who* and in *American Men of Science*. Suffice it to say, that since he graduated from the University of Nebraska he was prominently identified with educational work in the University of Nebraska, Washington State College, the University of Minnesota, the New York State Agricultural Experiment Station and Cornell University, and Massachusetts State College, respectively. Through these activities and his many other social and scientific contacts his abilities became evident to the extent that he had bestowed upon him practically every consideration of honor, friendship, and respect that his friends and associates had at their disposal.

"In 1924, he was selected by President Coolidge as the only eastern representative on the Agricultural Conference Commission; and more recently, when the funds under the Frasch Foundation for research in agriculture became available, he was selected as the first director to organize and administer the investigations undertaken—a relationship terminated by his death. To those who knew him intimately, there was no surprise that he received these recognitions in a field where fairness was of paramount consideration and where bias and

prejudice were unthinkable. It was because of these personal qualities that he made his greatest contribution to education. In the recent history of Massachusetts State College the author makes the following characteristic statement:—'President Roscoe Thatcher—people notice him quickly, then look a second time. There is something about his appearance—the Titan body, the deeply lined open face—that suggests the Nebraskian prairies where he spent his youth. There is nothing temperamentally timid about this man. He is making a good impression particularly upon his staff. They like his genuineness, his courage, his horse sense, even his occasional bluntness.'

"This is a fair and comprehensive statement of the qualities for which those who loved him most knew him best. I know of no finer tribute. His contact with educators and educational policies engendered a spirit of frankness, fair consideration, and confidence unfortunately too rare, but nevertheless so very essential to efficient and inspired service and satisfactory administration. His life was a success except that it terminated all too soon. At sixty-one he was still ready, eager, and qualified to make many more notable contributions to agricultural research."

INDEX